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SOME PODZOL SOILS OF ALBERTA

S. PAWLUK

Alberta Soil Survey, Research Council of Alberta, Edmonton, Alberta

[Received for publication February 16, 1959]

ABSTRACT

Recent exploratory surveys in the northern sections of Alberta revealed many soils morphologically similar to podzols. A laboratory study was carried out to obtain a better understanding of the genesis and morphology of these soils.

Chemical analyses showed the percentage base saturation and pH to be higher than for typical podzols.

Physical analyses showed slight increases in clay content in the B horizons and decreases in the A horizons when compared to the parent material.

From mineralogical studies of the profiles, the following weathering sequences were established: feldspars > quartz; chlorite > biotite > muscovite; hematite > horneblende > garnet ≥ magnetite. X-ray diffraction data showed illite, montmorillonite-illite mixed layering, montmorillonite, and kaolinite as being the principal clay minerals present in the A and C horizons. The clay mineral components of the B horizons were primarily chlorite-like with lesser amounts of kaolinite. Analyses indicated that the chlorite-like mineral lacked properties attributed to well crystallized chlorites and provided strong evidence in favour of authigenic origin.

Data obtained in this study showed the genesis of these soils to be somewhat different from that reported for podzols elsewhere although the process of formation evidently was primarily chemical.

INTRODUCTION

Recent exploratory surveys have revealed many areas with soils morphologically similar to podzols described in the literature (13), hitherto not considered to be of any significance in Alberta. The use of helicopters for survey in the heavily forested regions of the northern sections in the province provided a means by which these soils could be examined and described.

Literature on podzol soils and their formation is exceedingly voluminous on account of their broad distribution throughout the world. Gedroiz' early papers in Europe were among the first in which the chemical aspect of podzol formation was outlined (7). While Gedroiz based his theories largely upon mass action in chemical reactions, Mattson and Gustafsson (14) later pointed out the significant role of organic and inorganic colloids and their electrokinetic properties in the genesis of podzols. A study on the constitution of organic matter associated with podzols and its role in podzolization has recently been published in Canada (20). In addition, numerous other papers have been published on the podzol soils of the northern and northeastern regions of the United States (13).

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INTRODUCTION

Recent exploratory surveys have revealed many areas with soils morphologically similar to podzols described in the literature (13), hitherto not considered to be of any significance in Alberta. The use of helicopters for survey in the heavily forested regions of the northern sections in the province provided a means by which these soils could be examined and described.

Literature on podzol soils and their formation is exceedingly voluminous on account of their broad distribution throughout the world. Gedroiz' early papers in Europe were among the first in which the chemical aspect of podzol formation was outlined (7). While Gedroiz based his theories largely upon mass action in chemical reactions, Mattson and Gustafsson (14) later pointed out the significant role of organic and inorganic colloids and their electrokinetic properties in the genesis of podzols. A study on the constitution of organic matter associated with podzols and its role in podzolization has recently been published in Canada (20). In addition, numerous other papers have been published on the podzol soils of the northern and northeastern regions of the United States (13).

Despite differing theories on the mode of formation, data presented from analyses of podzols are similar in most respects. Morphologically, the sola have an unincorporated organic layer on the surface above an eluvial white Ae horizon. The light coloured Ae horizon is underlain by an organic B_h and/or a brown Bir horizon. Depth of horizons depends upon the degree of profile development. Chemically, the sola are strongly to extremely acid with low pHs and base saturation. The Ae is highly siliceous and has been somewhat depleted of iron and aluminium while the Bir exhibits a definite accumulation of these sesquioxides. A B_h horizon may or may not be present. Physically, the B horizon may or may not be characterized by clay accumulation. Often some of the material in the B may be cemented or indurated. Weathering of minerals in podzols has been studied by Van der Marel (24). He found severe weathering of amphiboles and epidotes while plagioclases had undergone only a slight degree of decomposition. He reported that authigenic boehmite and kaolinite formed as a result of synthesis. Tedrow (20), however, found little change in clay mineral composition in his study of podzol profiles.

MATERIALS AND METHODS

A study of Alberta podzols was prompted by preliminary laboratory analyses, the data of which do not agree with some of the chemical properties attributed to typical podzols. The pHs and the percentage of base saturation of the soil horizons are higher than their counterparts described in the literature. It is realized that these soils do not meet all requirements of the typical podzol previously discussed; however, because of their morphological similarity the term "podzol" is used in this paper. Complete analyses were done for a number of these soils in order to confirm the abnormalities mentioned and to try to explain them. The mineralogical, physical, and chemical procedures followed in the study are selected for their usefulness in providing data which might serve as a criteria for characterizing the soils, both morphologically and genetically.

Two soil profiles located about 50 miles apart near Ft. McMurray (Alberta map sheet 74-D) were selected. The area lies between 56°30 and 57° north latitude and between 111° and 112° west longitude. The parent material in the area is primarily sand with varying relief. Modes of deposition also vary; the region includes glacial and glacial fluviatile (comprised of fans, deltas, aprons, and pitted outwash) deposits. Vegetative cover in the podzol regions is primarily comprised of jackpine (*Pinus banksiana*) and aspen (*Populus tremuloides*) forest with an understorey of green alder (*Almus crispa*) and paper birch (*Betula papyrifera*). The ground cover is largely composed of kinnickennic (*Arctostaphylos uva-ursi*), blueberry (*Vaccinium vitis—idaea*) and hairy rye grass (*Elymus innovatus*).

The climate of the Fort McMurray region is dry sub-humid with relatively low precipitation and wide annual extremes in temperature. The mean annual precipitation is approximately 14 inches, of which 60 per cent falls in the months of June, July, and August. Thirty per cent of the precipitation is in the form of snow. Approximately 58 per cent of the rainfall occurs as showers of less than 0.5 inches and 83 per cent received

is less than 1.0 inches for any one continuous period. The annual water deficiency is reported to be 2 to 4 inches (calculated on the basis of Thornthwaite's equations). The average minimum January temperature recorded for Fort McMurray is in the vicinity of −58°F. The average maximum July temperature recorded is 88°F. with a monthly average of 60°F. The vegetative period begins approximately April 30 and extends to October 1.

The samples are from two morphologically similar profiles and are reasonably representative of the podzol soils encountered in the dry subhumid climatic area described above.

A brief description of the profile is as follows:

Horizon	Depth (in.)	Description
O(A_o)	3–0	Undecomposed and semidecomposed leaves and twigs. Fibrous structure.
Ae(A_2)	0–4	Whitish sand 10YR 8/0 (moist and dry). Single grain structure and loose consistency in both the dry and moist states.
Bir(B_2)	4–9	Sand, strong brown when moist 7.5YR 5/6, turns to yellowish brown 10YR 5/6 upon drying. Single grain structure. The consistency is somewhat soft in the dry state and very friable when moist.
BC(B_3)	9–28	Yellow brown sand 10YR 5/6 when moist and pale brown when dry. Single grain structure with loose consistency in both the dry and moist states.
C	28+	Very pale brown sand 10YR 7/4 (moist and dry). Single grain structure and loose consistency in the dry and moist states.

The horizons described were carefully sampled at each site, a quart container full being taken in each case. The conducted analyses are according to procedures commonly used in soil research.

Mechanical analyses were carried out according to the modified procedure for pipette analyses (22). Sand fractions were separated by dry sieving. Nitrogen, organic and inorganic carbon were determined according to the procedures outlined in A.O.A.C. (1). Exchangeable metallic cations were extracted from the soil with NH_4Ac (pH7). Total cation exchange capacities were determined by summation of the exchangeable cations determined in the soil. The NH_4Ac extracts were analysed for exchangeable calcium and magnesium by the versene method while exchangeable sodium and potassium were measured with a Perkin-Elmer flame photometer. Exchangeable hydrogen was determined by leaching the soil with 0.5N BaAc and titrating the leachate with O.IN NaOH using phenolphthalein as indicator. Details of the procedures are given elsewhere (3,16,19). The soil paste method was followed for pH determination (6). Procedures outlined by Robinson (18) were used for total fusion analyses. Free iron was removed with sodium hydrosulphite buffered at a

pH of 6 with 3 per cent NaOH (13) while free silica and alumina were removed by boiling with a 5 per cent solution of Na_2CO_3 for a period of 5 minutes. Quantitative estimates of their percentages were determined by colorimetric techniques (4, 5, 17). Cation exchange analyses were based on air-dry weight. The remaining analyses were based on oven-dry weight. The mineralogical composition of each major horizon (A, B, C) was determined. The light, intermediate, and heavy mineral fractions of the very fine sand were evaluated. A staining technique was employed to determine the composition of the light mineral fraction while standard petrographic procedures were followed for the remaining fractions.

A Norelco high angle geiger counter X-ray spectrometer with a copper target was used for analysing clays on oriented slides.

RESULTS AND DISCUSSIONS

Particle Size Distribution

Results for mechanical analyses are reported in Table 1. The data indicate an accumulation of clays in the Bir horizon whereas the Ae horizon is practically devoid of any clay. It is evident that clay has been transposed from the A to the B horizon even though the amounts are low. The parent materials of both profiles are largely composed of coarse, medium and fine sands.

pH

Data for pH measurements are shown in Table 2. The pH values varied from 5.6 to 6.2. The reason for the discrepancy between the high acidity measurements of typical podzols and the values obtained in the present study is not understood. The data indicate that podzolization can occur under slightly acid conditions. However, the seasonal variation in soil pH (2) may partly account for the values reported being so high.

TABLE 1.—MECHANICAL COMPOSITION OF TWO ALBERTA PODZOLS

Profile and Horizon	Sand						Silt % 0.05—0.002 mm.	Clay %	
	vcs 2.0—1.0 mm.	cs 1.0—0.5 mm.	ms 0.5—0.25 mm.	fs 0.25—0.10 mm.	vfs 0.10—0.05 mm.	Total		cc 2–0.2 microns	fc 0.2 microns
Profile 1									
Ae	3.8	65.1	28.2	2.3	0.6	100.0	tr.	tr.	0.0
Bir	15.6	28.4	28.6	14.5	6.3	93.4	2.6	3.2	0.8
BC	16.4	26.8	31.6	21.3	2.0	98.1	0.8	0.8	0.3
C	2.6	13.5	35.3	41.4	4.5	97.3	1.7	1.0	0.0
Profile 2									
Ae	2.5	14.5	33.4	38.2	5.1	93.7	5.9	0.4	0.0
Bir	1.8	13.7	25.9	37.8	6.8	86.0	9.7	4.3	2.8
BC	1.7	11.2	26.4	45.2	7.2	91.7	4.3	2.6	1.4
C	1.3	9.3	32.6	45.2	5.8	94.2	2.8	2.0	1.0

TABLE 2.—NITROGEN, ORGANIC CARBON, REACTION AND EXCHANGEABLE CATIONS OF TWO ALBERTA PODZOLS

Profile and Horizon	Nitrogen %	Organic carbon %	C/N	pH	Exchangeable cations*					Percentage base saturation**	Cation exchange capacity***
					Ca	Mg	K	Na	H		
Profile 1											
Ae	0.001	0.05	50	5.6	0.6	0.3	tr	0.0	0.1	90	1.0
Bir	0.009	0.49	54	6.1	0.8	0.2	tr	0.0	1.2	45	2.2
BC	0.002	0.04	16	6.2	0.5	0.2	tr	0.0	0.4	65	1.1
C	0.002	0.03	15	6.2	0.8	0.3	tr	0.0	0.1	92	1.2
Profile 2											
O	0.211	5.54	26	5.9	15.5	1.9	0.2	0.2	6.1	75	23.9
Ae	0.010	0.19	19	5.8	0.7	0.2	tr	tr	0.4	69	1.3
Bir	0.011	0.14	13	6.2	0.8	0.2	tr	tr	0.9	53	1.9
BC	0.005	0.05	10	6.2	1.1	0.2	tr	tr	0.4	76	1.7
C	0.003	0.03	10	6.1	0.9	0.3	tr	tr	0.4	75	1.6

*M.e. per 100 gm. soil
**Based on C.E.C. by summation
***Determined by summation and reported as m.e. per 100 gm. soil

TABLE 3.—CHEMICAL COMPOSITION AND FREE OXIDES IN ALBERTA PODZOLS

Profile and Horizon	Chemical composition									Free oxides		
	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	Hyg.H_2O %	Loss on ignition %	Si_2O %	Al_2O_3 %	Fe_2O_3 %
Profile 1												
Ae	97.56	0.17	0.33	0.08	0.11	0.60	0.06	0.05	0.04	0.84	0.06	0.06
Bir	94.21	1.46	3.17	0.16	0.23	1.12	0.60	0.51	1.21	0.12	0.32	0.70
BC	96.25	0.64	1.70	0.16	0.36	1.05	0.46	0.15	0.48	—	—	—
C	95.62	0.46	1.47	0.12	0.36	1.00	0.52	0.10	0.35	0.44	0.08	0.38
Profile 2												
Ae	94.22	0.31	1.99	0.16	0.41	0.77	0.68	0.19	0.68	0.92	0.08	0.08
Bir	92.30	0.97	3.20	0.32	0.35	0.77	0.72	0.43	0.75	0.42	0.38	0.52
BC	92.90	0.77	2.93	0.24	0.77	0.79	0.68	0.27	0.56	—	—	—
C	92.34	0.87	2.82	1.63	0.72	0.67	0.74	0.23	0.55	0.45	0.20	0.24

Exchangeable Cations and Base Saturation

Analyses for exchangeable cations and base saturation are presented in Table 2. High values obtained for base saturation bear out the soil pH data. The minimum value for base saturation was 45 per cent which is generally higher than those reported elsewhere for podzols (13). Other exchangeable cations are present in ratios close to those reported for other podzols.

Organic Matter

Carbon/Nitrogen ratios are also reported in Table 2. The ratios are fairly wide at the surface and become progressively narrower with downward progression. Data suggest either active decomposition in the Ae and Bir horizons or selective movement of organic matter. Similar results for sandy soils are reported elsewhere.*

*Pawluk, S. A study of some forest soil characteristics and their relation to jackpine growth. Unpublished Ph.D. thesis, University of Minnesota. 1957.

TABLE 4.—COMPOSITION OF THE HEAVY MINERAL FRACTION IN ALBERTA PODZOLS

Minerals	Profile 1		Profile 2		
	B	C	A	B	C
	%	%	%	%	%
Hornblende, dark green and black	5±1	6±1	7±1	6±1	5±1
green	10±1	8±1	18±1	11±1	10±1
brown	1±1	—	1±1	1±1	1±1
brown-green	1±1	pr*	2±1	2±1	1±1
altered	4±1	4±1	5±1	3±1	4±1
bleached	3±1	pr*	1±1	1±1	3±1
Total	22±2	19±1	34±2	25±2	28±2
Magnetite	11±1	7±1	14±1	10±1	7±1
Hematite	28±2	44±2	14±1	18±1	28±2
Hypersthene	6±1	2±1	4±1	4±1	3±1
Zircon	2±1	—	pr*	1±1	1±1
Garnet, white	14±1	10±1	15±1	14±1	10±1
pink	3±1	1±1	1±1	1±1	1±1
red	—	—	pr*	1±1	—
brown	—	1±1	—	—	—
Total	17±1	12±1	17±1	16±1	11±1
Pyroxene (monoclinic)	1±1	1±1	pr*	2±1	2±1
Epidote	4±1	2±1	4±1	5±1	3±1
Tourmaline	pr*	2±1	2±1	3±1	3±1
Leucoxene	1±1	2±1	—	2±1	2±1
Apatite	1±1	2±1	—	1±1	3±1
Topaz	—	—	—	pr*	—
Tremolite	pr*	—	—	2±1	1±1
Enstantite	2±1	1±1	1±1	pr*	1±1
Sillimanite, unaltered	—	—	pr*	1±1	1±1
altered to white	—	—	2±1	1±1	—
Titanite	pr*	4±1	2±1	2±1	3±1
Staurolite	—	pr*	1±1	pr*	pr*
Rutile	pr*	pr*	2±1	pr*	1±1
Monozite	pr*	—	pr*	—	pr*
Argenine	pr*	pr*	pr*	—	—
Unindentified	pr*	1±1	pr*	2±1	1±1

*Present in quantities< 1±1=

Total Fusion Analyses and Free Oxides

The data for chemical composition and free oxides are reported in Table 3. High percentages of silica in all the soil samples reflect the large amount of quartz present. The low aluminium percentage further indicates that the major portion of the sand is quartzitic; this is especially true of the Ae horizons. Free silica has its highest concentration in the Ae horizon while iron and aluminium have their highest concentrations in the Bir horizon. There is a well-defined accumulation of sesquioxides in both Bir horizons.

Mineralogical Analyses of the Sand Fraction with Diameter Limits between .10 and .05 mm.

Data for mineralogical analyses are shown in Tables 4 and 5. Mineral composition of the heavy fraction (specific gravity greater than 2.96) is shown in Table 4. Percentage error is calculated with the use of previously prepared statistical computations (10). Horneblende, magnetite, hematite and garnet constitute a major portion of the mineral content in this fraction. A wide variety of other minerals are also present in minute amounts. A heavy mineral count is lacking for the A_2 horizon of Profile 1 since this horizon was almost completely devoid of heavy minerals in the size range studied; consequently it was not possible to obtain the number of individual grains required for a suitable statistical count. Heavy mineral counts show very little difference between similar horizons of the two profiles.

Weathering ratios between various minerals of the light (sp. gr. <2.70), intermediate (sp.gr. 2.70-2.96), and heavy (sp.gr. >2.96) fractions are shown in Table 5. The index minerals used for this study are quartz, muscovite, and magnetite for the light, intermediate and heavy fractions consecutively. These minerals are considered to be stable or at least metastable (23). The selection of these minerals as index minerals is based on their presence in quantities large enough to provide statistically reliable calculations.

Assuming that little or no weathering occurred in the C horizon it may be concluded that weathering of the mineral fraction between diameter limits of .10 and .05 mm. can be expressed as follows: Ae > Bir > C.

TABLE 5.—WEATHERING RATIOS OF SOME MINERALS IN ALBERTA PODZOLS

(Based on means of duplicate samples)

Mineral Ratio	Horizon		
	A	B	C
Quartz/Feldspar	16.0	10.0	6.0
Biotite/Muscovite	0.5	1.3	2.0
Chlorite/Muscovite	4.0	12.0	21.0
Horneblende/Magnetite	2.1	2.3	3.4
Hematite/Magnetite	0.9	2.2	5.2
Garnet/Magnetite	1.2	1.6	1.7

FIGURE 1.—X-ray diffraction patterns of clay from Alberta podzol soils.

Weathering rates of the light mineral fraction may be expressed as feldspars > quartz.

Weathering rates of the intermediate mineral fraction may be expressed as chlorite > biotite > muscovite.

Weathering rates of the heavy mineral fraction may be expressed as hematite > horneblende > garnet ≥ magnetite.

X-ray Analyses of Clays

X-ray diffraction patterns of clays are shown in Figure 1. Analyses for the C horizon indicate that illite (8.8° peak) is the dominant clay mineral. Major quantities of illite-montmorillonite mixed layering and montmorillonite are present. Mixed layering is indicated by broad peaks between 8.8° and 6.3° which shift to larger "d" spacings upon glycol solvation and collapse to 8.8° upon heating to 500°C. Minor amounts of kaolinite (12.4° and 24.9° peaks) as well as traces of chlorite are also evident. The 26.6° and 20.8° peaks are indicative of minor amounts of quartz.

Clay in the Ae horizon of Profile 1 is present only in trace quantities. The clay minerals are primarily illite, montmorillonite, illite-montmorillonite mixed layering and kaolinite; all being present in more or less equal amounts. Quartz is present only in minor portions. The dominant clay mineral present in the Ae horizon of Profile 2 is illite. A major amount of illite-montmorillonite mixed layering as well as minor amounts of kaolinite, montmorillonite and quartz are also indicated.

The mineral components of the clay fraction in the B horizon are chlorite-like, kaolinite, and quartz. The chlorite-like mineral has properties that are somewhat different from well crystallized chlorites. Weaver (25) reports that the 14A° (6.2°) peak of chlorite should shift to 13.8A° upon heating to 500°C., whereas poorly crystalline chlorites are reported to be destroyed at temperatures of 400°C. to 450°C. leaving only the 12.4° kaolinite reflection. The corresponding peak in this study is found to be lowered by firing at 210°C., becoming diffuse and disappearing when heated to 500°C., (Figures 1 and 2). The kaolinite peaks persist up to 510°C., (Figure 2). Glycol treatment had no effect upon the clay mineral. Moreover, Weaver reports the chlorite peak at 6.2° as rather weak for well crystallized chlorite whereas the 6.2° peak is the most pronounced in this study. Chemical analyses as shown in Table 6 do not substantiate the presence of a brucite layer in the chlorite-like mineral structure because of the low amounts of magnesium present. This suggests that aluminium, either hydrated or in the form of a hydroxide, occupies the interlayer

TABLE 6.—CHEMICAL COMPOSITION AND EXCHANGE CAPACITY OF CLAYS

Profile and Horizon	Chemical composition*								Exchange capacity**
	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	Na_2O %	K_2O %	Hyg.H_2O %	Loss on ignition %	
Profile 1									
Ae	63.24	21.38	1.85	2.23	0.00	2.04	2.56	5.52	—
Bir	65.45	21.56	2.64	1.73	0.00	1.32	2.69	3.21	42
C	59.63	21.86	3.95	1.93	0.02	2.32	2.55	4.31	41
Profile 2									
Ae	56.33	21.43	1.88	1.74	0.02	2.79	2.54	5.63	47
Bir	56.92	21.32	3.45	1.60	0.01	1.91	1.94	9.79	42
C	55.16	22.11	3.92	2.08	0.02	2.43	1.78	10.34	42

*Determined on calcium saturated clay
**M.e. per 100 gm. clay

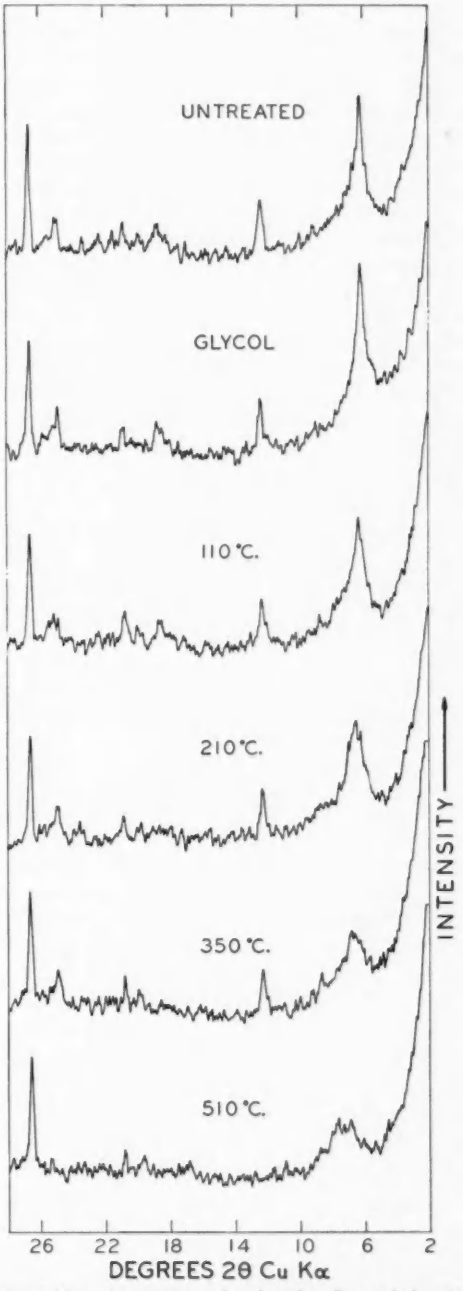

FIGURE 2.—X-ray diffraction patterns showing the effects of glycol and variable heat intensities on the 1.0—0.1 micron clay fraction of a podzol B.

position as was the case for chlorite-like minerals found in some soils in the United States (9, 11). Hathaway (9) reports soil clay minerals with 14A° spacings as occurring rather extensively. Furthermore, analyses for these minerals are in close agreement and, in general, compare favourably to those reported by the author. These clay minerals are referred to, in the literature, as "the dioctehedral analogue of vermiculite", "vermiculite", and "chlorite". The "dioctehedral analogue of vermiculite" and vermiculite clay minerals have structures which collapse to lower spacings upon heating. The collapse of the structures is attributed to gradual removal of water from the hydrated aluminium believed to occupy the interlayer positions. Figure 2 shows a gradual decrease in the intensity of the 14A° mineral in this study, but the structure does not collapse to lower spacings upon heating. The data suggests that the interlayer positions are probably occupied by hydroxyl forms of aluminium rather than the hydrated cation. The mineral would seem more closely related to the dioctehedral form of chlorite rather than vermiculite. Further investigations into the properties of the chlorite-like clay in these Alberta soils are being conducted.

DISCUSSION

It is proposed that, in spite of the rather unusually high base saturation of the soils concerned, these are podzol soils. The data obtained in this study show that the genesis is somewhat different from those reported elsewhere although the process of formation is evidently chemical. Results show that weathering of the minerals in the Ae and Bir horizons has taken place and quartz, chlorite, and amorphous materials have accumulated in the Bir horizon. The severe weathering of minerals in the surface horizon has occurred at pHs which are higher than is expected in podzols. A major portion of the feldspars in the .10 to .05 mm. size fraction is weathered out of the Ae horizon where only traces of clay remain. The type of clay minerals present in the Ae horizon is similar to that of the C horizon. Because of its resistance to weathering the proportion of kaolinite is somewhat higher in the Ae as compared to the content in the parent material and although in low quantities it also persists in the B horizon. There is also a decrease in illite content in the Ae horizon when compared to the content in the parent material.

The horizon of accumulation has considerably more clay than either adjacent horizon, and the mineral composition of this fraction is primarily quartz and chlorite with some kaolinite. Mineralogical analyses show a considerable amount of feldspar weathering. It is questionable as to whether or not weathering is active in the B horizon. It is the opinion of some prominent soil scientists that the B horizon in podzols forms from the bottom upward (13). If this should be the case, the upper portion of the B horizon may have been weathered while still part of the Ae or transition horizon during the earlier stages of podzol formation. With a progressive upward build-up of the illuvial horizon the lower Ae and transitional horizons would eventually be incorporated into the B horizon.

In the genesis of the soil it appears that dissolution of clay minerals, feldspars, as well as minerals of the heavy and intermediate fractions, occurs in the A horizon. Weathering ratios (Table 5) and heavy mineral

studies (Table 4) indicate that, in part at least, the dissolution is well advanced. Two possible mechanisms are suggested as explanations for chlorite synthesis in the B horizon. Partial dissolution of feldspars may result in the formation of skeletal alumino-silicates referred to as "degraded illite" (8) which could readily be transposed to the B horizon where they could be synthesized to a chlorite mineral by the addition of a layer of gibbsite to the basal surfaces. In view of the low amounts of magnesium released in dissolution of the minerals there would be a tendency for aluminum to substitute for magnesium (11). The presence of considerable amounts of alumina could result in its movement into the inner lattice spacings of montmorillonite. In addition displacement of potassium by alumina in illite would result in a structure similar to chlorite. As a possible alternative the formation of chlorite may be explained by synthesis from amorphous materials arising from dissolution of other minerals after the products of which have accumulated in the B horizon. In this case the synthesis of chlorite in these soils may have occurred as a consequence of the fairly high pH's, as is found to be the case in Henin's laboratory syntheses of montmorillonite clay minerals (10).

Chlorite is found in other Alberta soils. Chlorite is reported* as the only clay mineral present in the B_p horizon of a bisequal Grey Wooded soil in the foothill regions of Alberta, approximately 320 miles south and 140 miles west of the sampled profiles. The presence of chlorite is reported to occur in some of the Grey Wooded soils of Alberta although in no case is it the dominant clay mineral in any horizon**.

On the basis of the limited data available it appears that a chemical weathering and synthesis are responsible for the occurrence of chlorite-like minerals in B horizons of Alberta soils. The chlorite-like mineral so formed is at least partially the result of major changes in the crystal lattices of illite and montmorillonite and its formation is probably the result of dissolution. It appears very unlikely that the accumulation of a variety of clay minerals in the B horizon of Grey Wooded soils** is entirely the result of a similar process. The major transposition of clay minerals in Grey Wooded soils is better explained in terms of their electrokinetic and electrochemical properties as related to colloidal phenomena and ease of leaching rather than to any process which involves major changes in the crystal lattice.

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*Pawluk, S. The exchangeable cation status of some west central Alberta soils. Unpublished M. Sc. thesis, University of Alberta. 1955.

**Hortie, H. J. A comparative study of certain physical and mineralogical features of Grey Wooded Soils. Unpublished M. Sc. thesis, University of Alberta. 1952.

REFERENCES

1. Association of Official Agricultural Chemists. Official methods of analyses of the Assoc. Official Agr. Chemists. 8th ed. Washington, D.C. 1955.
2. Bowser, W. E., and J. N. Leat. Seasonal pH fluctuations in a Grey Wooded soil. Can. J. Soil Sci. 38:128–133. 1958.
3. Cheng, K. L., and R. H. Bray. Determination of calcium and magnesium in soil and plant material. Soil Sci. 72:449–458. 1951.
4. Corey, R. B., and M. L. Jackson. Silicate analyses by rapid semi-microchemical system. Anal. Chem. 25:624–628. 1953.
5. Davenport, Jr., W. H. Determination of aluminum in the presence of iron. Anal. Chem. 21:710. 1949.
6. Doughty, J. L. The advantages of soil paste for routine pH determinations. Sci. Agr. 22:135–138. 1941.
7. Gedroiz, K. K. Soil absorbing complex and the absorbed soil cations as a basis of genetic soil classification. People's Commissariat of Agriculture. Nossov Agr. Expt. Sta., Agro. Chemical Div., Paper 38. Leningrad.
8. Grim, R. E. Clay mineralogy. McGraw-Hill Book Co., New York, N.Y. 1953.
9. Hathaway, J. C. Studies of some vermiculite-type clay minerals. Clays and clay minerals. Natl. Acad. of Sci., Natl. Res. Council, Washington, D.C. Publ. 395, pp. 74–87. 1955.
10. Henin, S. Quelques résultats récents concernant la synthèse des minéraux argileux. Agrochimica 1:328–337. 1957.
11. Klages, M. G., and J. L. White. A chlorite-like mineral in Indiana soils. Soil Sci. Soc. Amer. Proc. 21:16–20. 1957.
12. Krumbein, W. C., and F. J. Pettijohn. Manual of recent sedimentary petrography. 1st ed. Appleton-Century-Crofts, Inc., New York, N.Y. 1939.
13. Lutz, H. J., and R. F. Chandler. Forest soils. 4th ed. John Wiley and Sons, Inc., New York, N.Y. 1949.
14. Mattson, S., and Y. Gustafson. The chemical characteristics of soil profiles. I. The podzol. Annals Roy. Agr. Coll. Sweden 1. 1926.
15. Mitchell, B. D., and R. C. Mackenzie. Removal of free iron oxide from clays. Soil Sci. 77:173–185. 1954.
16. Peech, M. Determination of exchangeable cations and exchange capacity of soils—rapid micro-methods utilizing centrifuge and spectrophotometer. Soil Sci. 59:25–38. 1945.
17. Robertson, G. The colorimetric determination of aluminum in silicate materials. J. Sc. Food Agr. 1:59–63. 1950.
18. Robinson, W. O. The fusion analyses of soils. Soil Sci. 59:7–11. 1945.
19. Russel, D. A., and G. S. Stanford. A laboratory manual for soil fertility students. 2nd ed. Wm. C. Brown Co., Dubuque, Iowa. 1954.
20. Schnitzer, M., and J. R. Wright. A note on the extraction of organic matter from the B horizon of a podzol soil. Can. J. Agr. Sci. 36:680–681. 1956.
21. Tedrow, J. C. F. Clay minerals in three podzol profiles. Soil Sci. Soc. Amer. Proc. 18:479–81. 1954.
22. Toogood, J. A., and T. W. Peters. Comparison of mechanical analysis of soils. Can. J. Agr. 33:159–171. 1953.
23. Twenhofel, W. H. Principles of sedimentation. 2nd ed. McGraw-Hill Book Co., Inc., New York, N.Y. 1950.
24. Van der Marel, H. W. Mineralogical composition of a heath podzol profile. Soil Sci. 67:193–207. 1949.
25. Weaver, C. E. Geologic interpretation of argillaceous sediments. Bull. Amer. Assoc. Petrol. Geol. 42:254–309. 1958.

RATE OF SOIL DRAINAGE FOLLOWING AN IRRIGATION.
II. EFFECTS ON DETERMINATION OF RATE OF CONSUMPTIVE USE[1]

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ABSTRACT

An investigation was conducted to determine the effects of soil drainage and other factors on consumptive use as measured by the soil sampling procedure. Four pairs of adjoining plots were established in four different fields in which the soil varied from coarse loamy sand to clay loam. One plot of each pair was kept in crop and the other was kept bare and covered. They were irrigated thoroughly, and their soil was sampled periodically for 20 days or longer to determine the soil moisture contents. Between samplings the bare plot was kept covered with a tarpaulin. The following results were obtained:

1. No really satisfactory method was developed for separating consumptive use from drainage during the initial period of 2 or more days following an irrigation. During this initial period, consumptive use occurred largely at the expense of free water that would otherwise have drained away. This situation continued longer with a fine-textured soil than with a coarse-textured soil.
2. By the procedure used in these tests, consumptive use was separated from drainage satisfactorily following the initial period after irrigation. After this initial period the rate of consumptive use decreased with time until the end of each test.
3. The rate of drainage was less in the cropped plots than in the covered plots, but the rate of total moisture reduction was greater.
4. When the total moisture lost from a bare covered plot was deducted from that lost from a cropped plot, the values thus obtained for consumptive use were much too low.
5. When the total moisture lost from the cropped plots was used as a measure of consumptive use, the results were often much too high.

It is concluded that no reliable method has yet been developed for routine determination of the rate of consumptive use by soil sampling.

INTRODUCTION

In the first paper of this series (18), studies were reported of the soil moisture content of the soil following an irrigation. In a covered soil, the logarithm of the moisture content was found to decrease at a constant rate with increase in the logarithm of time. In this present paper, studies are reported dealing, first, with the relationship between drainage and consumptive use and, second, with the reliability of the soil sampling procedure for determination of consumptive use.

The term "consumptive use" (16) is used in this paper to mean primarily the use of water from the soil by plants plus that evaporated from the surface of the soil. It also includes the rainfall intercepted by plants. It does not include water lost below the root area by deep percolation.

REVIEW OF LITERATURE

For determination of rates of consumptive use by the soil sampling procedure, it has been customary to take one set of samples following an irrigation, and one or more sets of samples prior to the next irrigation.

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The first set is taken as soon as the most rapid drainage has occurred and the soil moisture is presumed to be at "field capacity". The rate of consumptive use is then determined by calculating the difference in moisture content between paired sets of samples, and dividing by the interval in days to give the rate per day.

The question arises as to just when the initial rapid drainage has been completed. Veihmeyer and Hendrickson (4, 13) found that comparative equilibrium of moisture content was reached in 2 to 3 days, and considered this a suitable time to take the first samples in most soils. Others (3, 6, 10, 15, 16) have sampled at anywhere from 1 to 4 days after irrigating depending on soil texture. In 1953, however, Wilcox, Mason and McDougald (17) reported that by taking the first samples at 1 to 3 days after an irrigation, consumptive use values were obtained that were as high as irrigation requirements. In 1954, Robins, Pruitt and Gardner (8) found that sampling at 2 days and 8 days gave consumptive use values 23 per cent too high. In 1956, Stevenson (11) reported similar experimental results. A study of the literature indicates, therefore, that most workers accept a sampling time of 1 to 3 or 4 days after irrigating as being suitable, while at least two have found the results thus obtained to be too high.

The effects of relative moisture content of the soil on consumptive use have been studied by a number of workers. Some have found (12, 14) that the rate of transpiration was practically the same from the time of irrigation until quite close to the wilting point. Others have reported a reduction in transpiration only after two-thirds (7), three-fifths (17) or even about one-third (9) of the available moisture had been used up. Still others (2, 15) have found a progressive reduction in rate of transpiration or consumptive use from immediately after irrigating until wilting. It appears from a review of the literature that the varying results obtained have been influenced not only by moisture content but by other factors such as kind of soil, kind of plant, and root proliferation.

TABLE 1.—LIST OF COMPARABLE PAIRS OF COVERED AND CROPPED PLOTS

Year	Test No.	Soil texture	Depth of sampling	Duration of sampling	Number of holes sampled	Treatment
			feet	days		
1954	4	Sandy loam	4	30	4	Covered
	5	Sandy loam	4	30	4	Alfalfa
1955	11	Silt loam	7	20	9	Covered
	12	Silt loam	7	20	9	Grass
1957	17	Loamy sand	6	64	9	Covered
	18	Loamy sand	6	20	9	Grass
	19	Clay loam	6	64	9	Covered
	20	Clay loam	6	40	9	Alfalfa

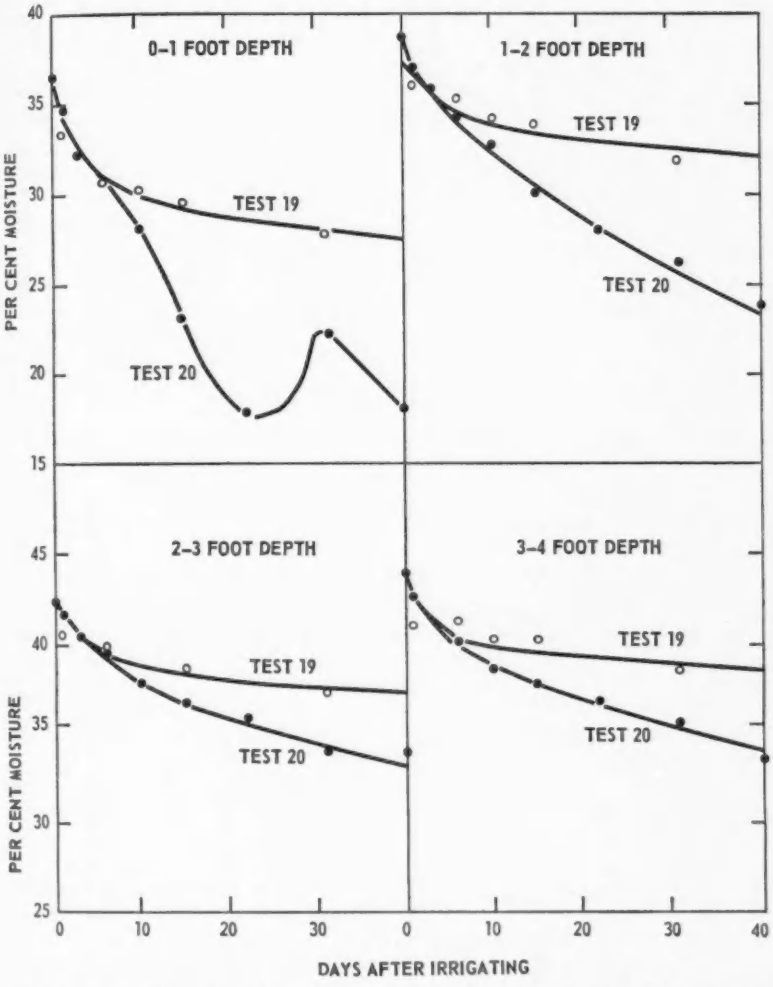

FIGURE 1. Comparison of moisture contents in top 4 feet of Test 19 (uncropped, covered) and those in Test 20 (alfalfa) in clay loam soil.

PROCEDURE

In the first paper of this series (18), 12 tests were reported in which the rate of drainage following irrigation was determined. The procedure used was to clear the soil of vegetation, irrigate it thoroughly, cover it to prevent evaporation, and sample periodically to determine the soil moisture contents. Results from four of these tests (numbers 4, 11, 17, 19) are used again in this present study. These four test plots were located immediately adjacent to established crops in which parallel tests were conducted as

indicated in Table 1. Test 5 was located in a 3-year stand of alfalfa, Test 12 in a pasture field of mixed grasses, Test 18 in tall oat grass, and Test 20 in a 5-year stand of alfalfa. Each test consisted of one plot only, 12 × 12 feet in area. Irrigation and soil sampling were conducted in these plots the same as in the parallel bare plots. The cropped plots, however, were not covered between soil samplings. Records were taken of rainfall, and the consumptive use values obtained in the four cropped plots were adjusted for any rain falling within the consumptive use intervals concerned.

It will be necessary to explain further details of the procedure as each step of the results obtained is presented below.

RESULTS

In some respects the results from all four of the cropped plots were similar. For conciseness, more detailed data will be given for only one of the four tests—Test 20. Some results from the other three tests will also be presented for comparison purposes.

Comparison of Cropped and Covered Plots

Some data on Test 19 have already been presented (18). In Test 20, soil samples were taken to a depth of 6 feet at 0, 1, 3, 6, 10, 15, 22, 31 and 40 days after irrigating. There was no sign of wilting in the alfalfa at 40 days.

Curves of moisture content versus time for the top 4 feet of Tests 19 and 20 are presented in Figure 1. The curves for Test 19 are drawn from equations for the 64-day period, as previously noted (18). Those for Test 20 were drawn free-hand through the points. The large kink in the 0-1 foot curve for Test 20 was caused by rainfall. It will be noted that the area between the pairs of curves lessened with greater depth. This area was relatively small in the fifth and sixth feet. It will also be noted that for several days after irrigating the curves were close together.

The depth of consumptive use in each cropped plot was determined as being that depth below which the rate of water loss was the same as in the parallel covered plot. Curves are given in Figure 2 showing the average moisture contents to the depths of consumptive use for all eight tests. The depths included in the averages shown were 0 to 3 feet in Tests 5, 12 and 18, and 0 to 6 feet in Test 20. Only the first 20 days of each test are shown. The curves for Tests 12, 18 and 20 have been adjusted for rainfall, by adding the rainfall to the total moisture losses. It should be noted that in Test 18 the plants showed evidence of wilting before the end of the test. Since no two pairs of these tests were run at the same time, the curve differences shown in Figure 2 are not exactly comparable.

Separation of Consumptive Use from Drainage Losses

Water was lost from the cropped plots both by consumptive use and by drainage. Some difficulty has been encountered in separating these two types of water loss. At first, it seemed logical simply to deduct the moisture contents in the cropped plots from those in the covered plots, and call the difference consumptive use. Such a procedure, however, has been found to lead to serious error. As pointed out in the first paper of this series (18), the rate of drainage from the soil is a function of its

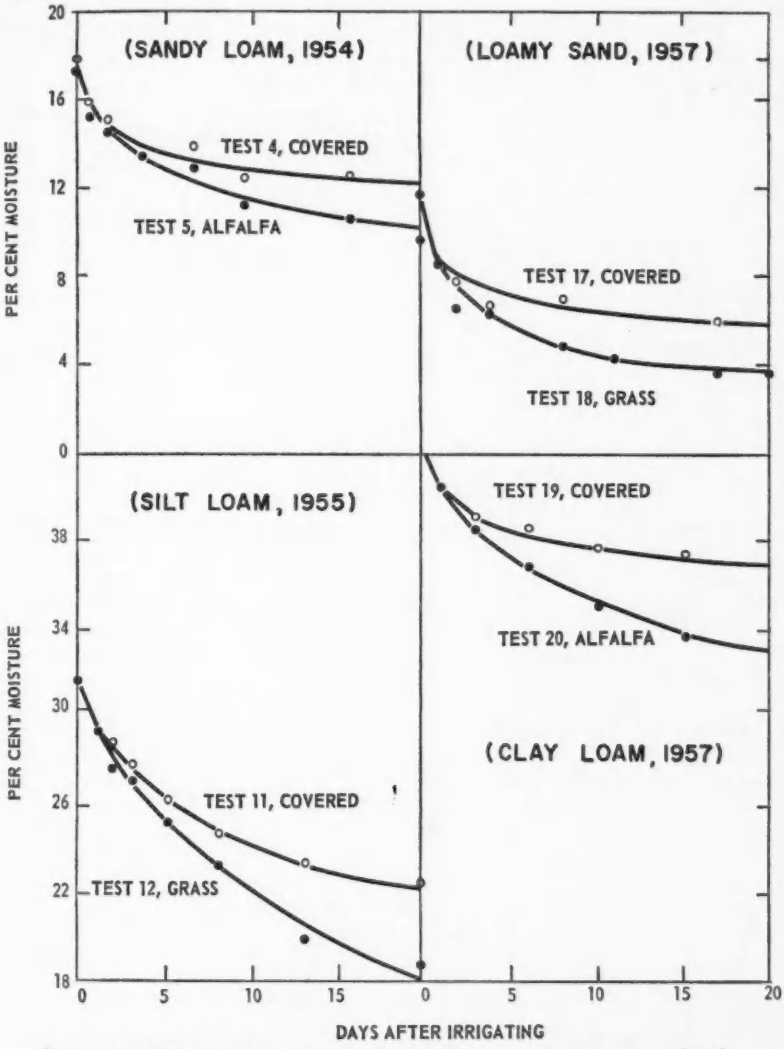

FIGURE 2. Moisture contents to root depth in four cropped plots compared to those in four parallel covered plots. The moisture contents are shown only up to 20 days after irrigating.

moisture content. Since the moisture content of the soil lessens more rapidly with time in the cropped plots than in the covered plots (Figure 2), the rate of moisture loss by drainage also lessens more rapidly. At any one time after irrigation, therefore, the rate of drainage in the cropped plots could not have been as great as in the respective covered plots. The rates of consumptive use, then, were higher than would be indicated by deducting the one set of moisture contents from the other set.

The rate of drainage from the soil is a function not only of the moisture content, but also of the soil moisture gradient. Since the gradients have proved to be different in the cropped plots from what they were in the covered plots (Figure 1), the differences in drainage rates between the two have undoubtedly been affected somewhat thereby. In these tests, however, no procedure was developed for assessing differences in drainage rates caused by differences in soil moisture gradients.

In order to separate consumptive use from drainage in the cropped plots, it was assumed that the rate of drainage in each cropped plot was the same as in the corresponding covered plot when the soil in the two plots had equal moisture contents. Any stated moisture content in a cropped plot occurred later (usually much later) in the covered plot. This meant that it was necessary to extrapolate the drainage curves for the covered plots for longer periods of time than those actually included in the tests.

The problem of separating consumptive use from drainage in the cropped plots was complicated by the fact that for a short time following irrigation the rate of loss of moisture from each cropped plot was practically the same as from the respective covered plot, as indicated in Figures 1 and 2. This meant that drainage plus consumptive use in the cropped plot was no greater, during that period, than drainage alone in the covered plot. The question arises as to whether the rate of consumptive use during this initial period could actually have been less than that following the initial period. As noted in the Review of Literature above, the rate of consumptive use does not increase following an irrigation (assuming weather conditions to be constant); some authors, indeed, report a definite decrease. Immediately following an irrigation, then, the rate of consumptive use is at least as great as it is later, perhaps greater. This leads to the conclusion that during the period when total moisture losses from the cropped and covered plots were equal, consumptive use was occurring almost entirely at the expense of water that would otherwise have drained away. During this initial period, then, drainage from each cropped plot was less than that from the covered plot, apparently largely because of consumptive use from free water in the cropped plot.

TABLE 2.—METHOD OF CALCULATION OF RATE OF CONSUMPTIVE USE. TEST 20, 0-6 FEET.

1	2	3	4	5	6	7	8	9
Time after irrigation	Test 20 moisture lost per day	Test 19 moisture lost per day	Test 20 minus Test 19	Test 20 mean moisture content*	Drainage per day from Test 19 chart	Test 20 consumptive use per day	Same from chart	Estimated drainage Test 20
days	%	%	%	%	%	%	%	%
0– 1	2.27	2.40	−.13	42.30	2.30	.00	.36	1.90
1– 2	1.10	1.14	−.04	40.62	1.26	.00	.36	.74
2– 3	.63	.64	−.01	39.76	.80	.00	.35	.28
3– 4	.57	.50	.07	39.17	.50	.07	.35	.22
4– 5	.51	.38	.13	38.63	.32	.19	.34	.17
5– 6	.48	.30	.18	38.14	.20	.28	.33	.15
6– 7	.45	.25	.20	37.68	.14	.31	.33	.12
7– 8	.42	.22	.20	37.26	.11	.31	.32	.10
8– 9	.39	.19	.20	36.85	.08	.31	.31	.08
9–10	.37	.17	.20	36.45	.07	.30	.30	.07

*The mean of the moisture content at the start and end of each day

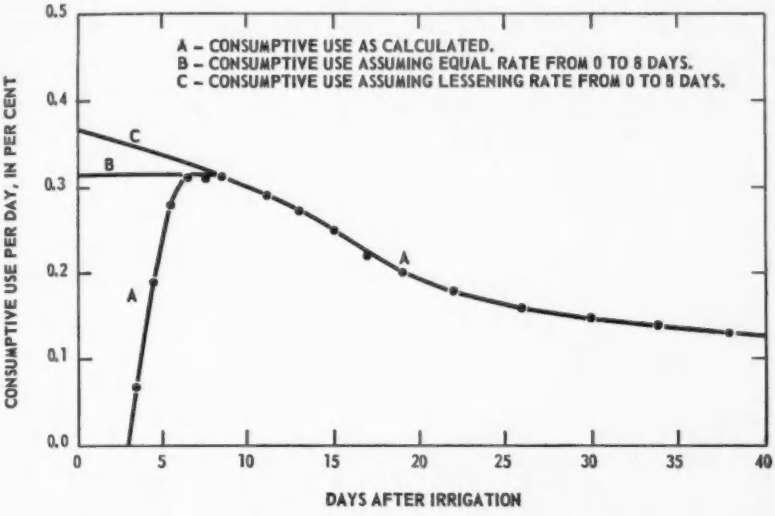

FIGURE 3. Calculated rates of consumptive use in Test 20, 0–6 feet.

It is on the basis of these conclusions that consumptive use has been separated from drainage in the cropped plots. As an example, calculations for the first 10 days of Test 20 are given in Table 2. Moisture content and moisture loss in Test 19 were determined progressively by calculating the equation relating each of these to time in days, charting the values on log-log paper (Figure 2 in the first paper of this series), and reading off the per cent moisture occurring at the centre of each time period on the chart. Moisture contents and moisture losses in Test 20 were determined by drawing lines free-hand through the points on the charts, as in Figure 2.

The values shown in the last five columns of Table 2 were determined as follows: (a) Each value in Column 5 is the average of the two moisture contents at the beginning and end of the period, as determined from the free-hand curve; (b) The values in Column 6 were obtained by locating the Column 5 values on the curve relating rate of moisture loss to moisture content in Test 19 (Figure 3 of the first paper of this series); (c) Column 7 was determined by deducting Column 6 from Column 2; (d) The values in Column 7 were charted against time (Figure 3). The values for the first 7 days were obviously too low, and Curve C in Figure 3 was assumed to be approximately correct. This curve gave the values shown in Column 8. (e) If Column 8 is correct, then actual drainage in Test 20 can be determined by deducting Column 8 from Column 2 to obtain Column 9.

Using the above procedure, rates of consumptive use were calculated for the other three cropped plots. The curves obtained are compared with the first 20 days of Test 20 in Figure 4. In each case, the consumptive use as measured increased at first, then lessened. Estimates of actual consumptive use during the initial period have been obtained by extrapolation of the curves to zero time.

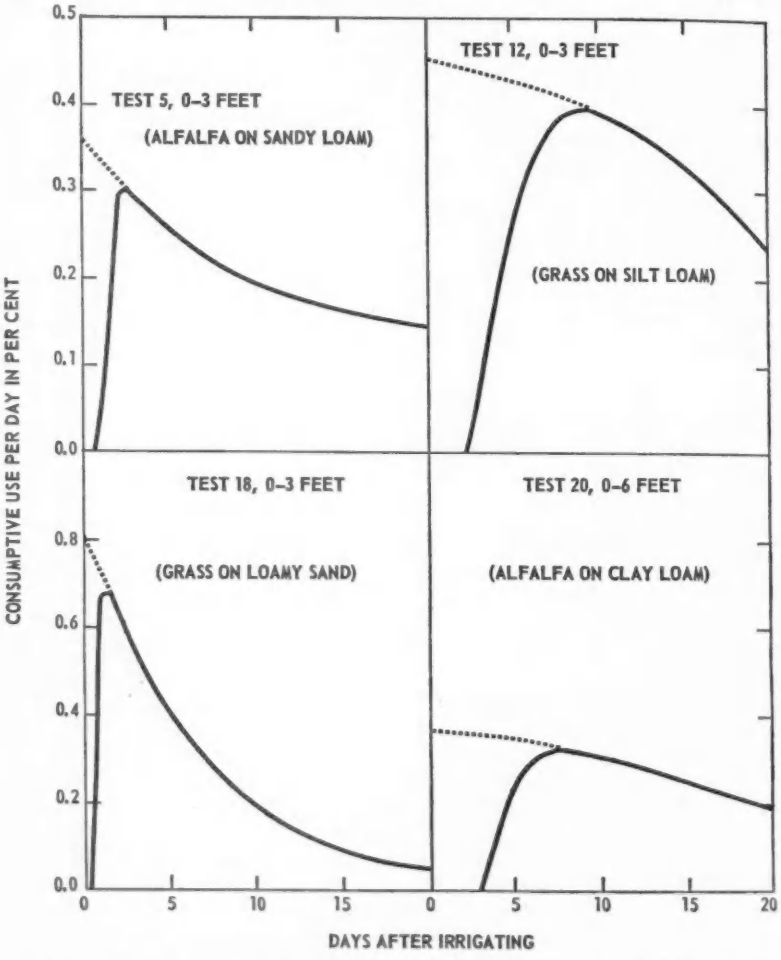

FIGURE 4. Consumptive use curves for all four cropped plots. Calculated curves are shown as continuous lines. Assumed extensions to zero time are shown as discontinuous lines.

The same procedure was used for separating consumptive use from drainage within each foot of depth. As an example, the results for Test 20 are illustrated in Figure 5. Per cent moisture is charted on a logarithmic scale in order to separate the curves from one another. The curves have been extended to zero time as illustrated in Figure 4. The 3-4 foot curve (not shown) is almost the same as the 2-3 foot curve. It will be noted that the rate of consumptive use tended to lessen with time at all depths. It will also be noted that consumptive use tended to lessen with depth. As pointed out by Wilcox and Mason (16), this can normally be expected to occur where irrigation is not delayed too long.

TABLE 3.—ERRORS IN DETERMINATION OF RATE OF CONSUMPTIVE USE BY SOIL SAMPLING. TEST 20, 0–6 FEET

1	2	3	4	5	6	7
Time after irrigation		Total moisture lost per day	Drainage loss per day in Test 19	Consumptive use per day	Per cent error if Column 3 is used to represent consumptive use*	Per cent error when Column 4 is deducted from Column 3**
First sampling	Second sampling					
days	*days*	%	%	%	%	%
1	8	.59	.49	.34	+74	−71
1	14	.48	.33	.32	+50	−53
1	20	.40	.25	.29	+38	−42
1	30	.32	.18	.25	+28	−39
2	8	.51	.38	.34	+50	−62
2	14	.42	.26	.31	+36	−55
2	20	.36	.20	.28	+29	−43
2	30	.29	.14	.24	+21	−37
4	20	.33	.15	.27	+22	−33
4	30	.27	.11	.23	+17	−30
8	20	.29	.10	.26	+12	−27
8	30	.23	.08	.21	+10	−29
14	30	.19	.05	.19	+00	−26

$$*\text{Error} = \frac{100\ (\text{Column 3 minus Column 5})}{\text{Column 5}}$$

$$**\text{Error} = \frac{100\ (\text{Column 3 minus Column 4 minus Column 5})}{\text{Column 5}}$$

Errors in Determination of Consumptive Use by Soil Sampling

When the rate of consumptive use is determined by sampling the soil soon after an irrigation and again later in the same irrigation interval, the difference in moisture content between the two sets of samples is produced not only by consumptive use but also by drainage. The question arises as to how much the drainage losses can influence the accuracy of the results.

In order to assess the degree of error involved in using the soil sampling method, it was necessary to accept some measure of consumptive use as a standard. For this purpose, the upper curves in Figure 4 were used as a basis for calculation of error by the methods which follow.

Two methods were used for determining the errors inherent in the soil sampling method. The consumptive use that would have been obtained by soil sampling was compared (by the first method) with the actual consumptive use during that same period, and (by the second method) with the actual consumptive use during the whole irrigation interval. Here the "actual" consumptive use means that represented by the upper curves in Figure 4.

Method 1 for Calculation of Error. For the determination of error by the first method, different periods of soil sampling following an irrigation were selected, as indicated for Test 20 in Table 3. Using total moisture loss during each period to represent consumptive use, the value obtained for 1 to 8 days after irrigating was 74 per cent too high. Taking the second sample at later dates reduced the error considerably. Taking the first sample at later dates, however, reduced the error still more. By taking the first sample 10 or more days after irrigating, the error would have been reasonably low.

TABLE 4.—ERRORS IN DETERMINATION OF RATE OF CONSUMPTIVE USE BY SOIL SAMPLING. TESTS 5, 12, 18

Time after irrigating		Per cent error using total moisture loss to represent consumptive use*			Per cent error using total loss minus loss from covered plot to represent consumptive use**		
First sampling	Second sampling	Test 5	Test 12	Test 18	Test 5	Test 12	Test 18
days	*days*	%	%	%	%	%	%
1	8	+108	+104	+15	−46	−88	−25
1	14	+ 76	+ 71	+12	−43	−53	−27
1	20	+ 57	+ 56	+10	−36	−49	−31
2	8	+ 75	+ 80	+ 6	−37	−35	−27
2	14	+ 49	+ 56	+ 3	−37	−40	−21
2	20	+ 38	+ 43	+ 3	−27	−54	−33
4	14	+ 25	+ 42	+ 3	−42	−48	−27
4	20	+ 21	+ 32	+ 2	−32	−45	−33
8	20	+ 12	+ 20	0	−23	−40	−43
14	20	+ 4	+ 9	0	− 9	−38	−66

$$*\text{Error} = \frac{100\ (\text{total moisture lost} - \text{consumptive use})}{\text{consumptive use}}$$

$$**\text{Error} = \frac{100\ (\text{total moisture lost} - \text{drainage from covered plot} - \text{consumptive use})}{\text{consumptive use}}$$

Similar data for the other three tests are summarized in Table 4. It will be noted that when total moisture loss from the cropped plots was used to represent consumptive use, the degree of overestimation was much less in Test 18 than in the other three tests. In Test 18, on a loamy sand, drainage was very rapid at first, then slowed right down. When total moisture loss from the cropped plot minus the drainage from the covered plot was used to represent consumptive use, the degree of underestimation was large in all four tests.

In using soil sampling by this method to determine rates of consumptive use, the question arises as to how soon after irrigating it would be safe to take the first samples. If we wished to reduce our degree of error to 10 per cent or less, we would have needed to delay sampling in these four tests for at least the following periods:

Test 5 — 9 days
Test 12 — 14 days
Test 18 — 1 day
Test 20 — 8 days

The initial periods of sampling that have heretofore been considered at this Station to be suitable for these four soils have been 2, 3, 1 and 4 days respectively, based on soil texture.

Method 2 for Calculation of Error. By the second method, in which the correct consumptive use was considered to be the average rate for a whole irrigation interval, it was necessary to determine when the cropped plots would have needed to be irrigated again. This was considered to be when the moisture content was reduced to 50 per cent of the available moisture content. The upper limit of available moisture was determined by a procedure that will be outlined in the third paper of this series. It

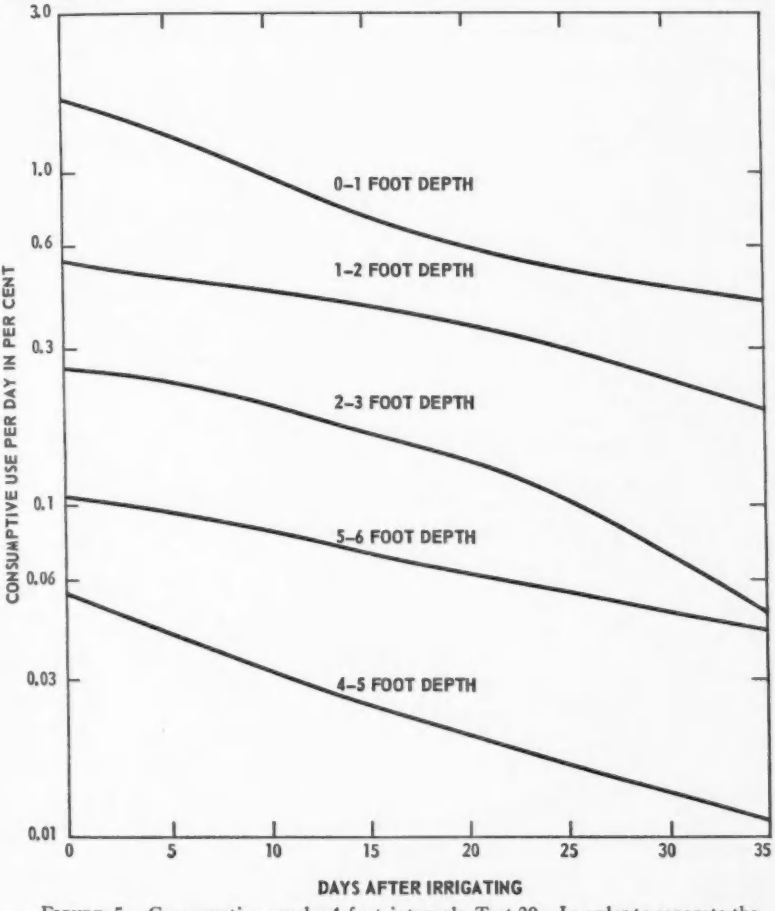

FIGURE 5. Consumptive use by 1-foot intervals, Test 20. In order to separate the five curves, the consumptive use scale is logarithmic.

was approximately equal to field capacity as usually determined in the field. The lower limit of available moisture (the wilting point) was determined with a pressure membrane apparatus. The 50 per cent points as thus determined were lower than the moisture contents at the end of the tests with Tests 5, 12 and 20. It was, therefore, necessary to extrapolate the moisture-time curves and the consumptive use-time curves in these tests to obtain all the required data.

The data obtained by this method are summarized in Table 5. Because of low consumptive use at 4-6 feet in Test 20, calculations were made for 0-4 feet only. The first days of soil sampling are those indicated in the table; the final days were those required to reach 50 per cent of available moisture. It will be seen that the errors are much lower than those indicated in Tables 3 and 4.

TABLE 5.—ERRORS IN DETERMINATION OF RATE OF CONSUMPTIVE USE DURING FULL IRRIGATION INTERVAL

	Test 5	Test 12	Test 18	Test 20
Soil depth, in feet	0–3	0–3	0–3	0–4
Moisture content at 50% available moisture, in %	9.1	16.3	4.2	23.4
Days after irrigating required to reach this moisture content	27	32	7	50
Average daily consumptive use to this time, in %	0.192	0.316	0.523	0.202
Assumed correct day of first sampling	2	3	1	4
Consumptive use as determined between sampling dates, in %	0.231	0.361	0.545	0.213
Error of determination, in %	+20	+14	+4	+5

These results indicate that in some cases it may be reasonably safe to sample the soil at 1 to 4 days after an irrigation and again just prior to the next irrigation. Where the rate of drainage between the two sampling dates is low compared to the rate of consumptive use, as in Tests 18 and 20, the error may be small. Where the rate of drainage is not known, there may be a substantial overestimation of the rate of consumptive use. The overestimation can be quite large if the first day of sampling is too soon or if the second day of sampling is not toward the end of the irrigation interval.

There is, of course, a serious difficulty in this approach, and that is that the rate of drainage is difficult to determine in routine work and is, therefore, not known in most cases. If it is assumed that the rate of drainage is small between the sampling dates, this can lead to serious errors. It is obvious that more fundamental work is needed before the soil sampling method can be used with any degree of reliability.

Conclusions

The results of this investigation justify the following conclusions:

1. No satisfactory method was developed for separating the rate of consumptive use from the rate of drainage during the initial period following an irrigation.

2. Following this initial period, however, consumptive use was separated from drainage by measuring the rate of drainage in an uncropped covered plot adjacent to the cropped plot, and by deducting from the total moisture losses in the cropped plot the drainage losses from the covered plot at equal soil moisture contents.

3. Immediately following an irrigation, consumptive use was largely at the expense of water that would otherwise have been lost by drainage.

4. After this initial period following an irrigation, the rate of consumptive use decreased progressively. Whether or not this held true during the initial period, as well, could not be determined by field methods.

5. The rate of consumptive use lessened progressively with greater depth, at least within the period ending at 50 per cent of available moisture in the soil.

6. Where crops were growing, drainage from the root area decreased more rapidly than where the soil was uncropped and covered. It continued to occur in substantial amounts, however, for much longer periods than has generally been assumed to be the case.

7. When the total moisture lost from a bare covered plot was deducted from that lost from a cropped plot and the difference was called consumptive use, the values thus obtained were much too low.

8. On the other hand, when soil samples were taken 1 to 4 days after an irrigation and again later in the irrigation interval, and the difference in moisture content was called consumptive use, the results were usually much too high.

9. Although under certain conditions the error by soil sampling may be negligible, it seems almost impossible to be certain that such conditions exist. There is as yet no suitable routine method whereby one can be certain that the results are reliable.

10. Further work needs to be done before the soil sampling method can be used with full confidence for determinaton of the rate of consumptive use.

REFERENCES

1. Allmendinger, D. F., A. L. Kenworthy, and E. L. Overholser. The carbon dioxide intake of apple leaves as affected by reducing the available soil water to different levels. Proc. Amer. Soc. Hort. Sci. 42:133–140. 1943.
2. Bloodworth, M. E., J. B. Page, and W. R. Cowley. Some applications of the thermoelectric method for measuring water flow rates in plants. Agron. J. 48:222–228. 1956.
3. Corey, G. L., and V. I. Myers. Irrigation of Russett Burbank potatoes in Idaho. Idaho Agr. Expt. Sta. Bull 246. 1955.
4. Hendrickson, A. H., and F. J. Veihmeyer. Irrigation experiments with peaches in California. Calif. Agr. Expt. Sta. Bull. 479. 1929.
5. Houston, C. E. Consumptive use of water by alfalfa in Western Nevada. Nevada Agr. Expt. Sta. Bull. 191. 1955.
6. Lewis, M. R., R. A. Work, and W. W. Aldrich. Studies of the irrigation of pear orchards on heavy soil near Medford, Oregon. U.S.D.A. Tech. Bull. 432. 1934.
7. Martin, E. V. Effect of soil moisture on growth and transpiration in *Helianthus annuus*. Plant Physiol. 15:449–466. 1940.
8. Robins, J. S., W. O. Pruitt, and W. H. Gardner. Unsaturated flow of water in field soils and its effect on soil moisture investigations. Soil Sci. Soc. Amer. Proc. 18: 344–347. 1954.
9. Schneider, G. W., and N. F. Childers. Influence of soil moisture on photosynthesis, respiration, and transpiration of apple leaves. Plant Physiol. 16:565–583. 1941.
10. Shaw, R. H., and J. R. Runkles. Soil moisture and water utilization in Iowa. Agron. J. 48:313–318. 1956.
11. Stevenson, D. S. Percolation of soil water as related to consumptive use. M. Sc. thesis, State College of Oregon. 1956.
12. Veihmeyer, F. J. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia 2:125–292. 1927.
13. Veihmeyer, F. J., and A. H. Hendrickson. The moisture equivalent as a measure of the field capacity of soils. Soil Sci. 32:181–193. 1931.
14. Veihmeyer, F. J., and A. H. Hendrickson. Does transpiration decrease as the soil moisture decreases? Trans. Amer. Geophys. Union 36:425–448. 1955.
15. West, E. S., and O. Perkman. Effect of soil moisture on transpiration. Australian J. Agr. Research 4:325–333. 1933.
16. Wilcox, J. C., and J. L. Mason. Consumptive use of water in orchard soils. I. Effects of soil depth. Can. J. Agr. Sci. 33:101–115. 1953.
17. Wilcox, J. C., J. L. Mason, and J. M. McDougald. Consumptive use of water in orchard soils. II. Effects of evaporating power of air and of length of irrigation interval. Can. J. Agr. Sci. 33:231–245. 1953.
18. Wilcox, J. C. Rate of soil drainage following an irrigation. I. Nature of soil drainage curves. Can. J. Soil Sci. 39:107–119. 1959.

EFFECTS OF LONG-TERM SURFACE APPLICATIONS OF LIMESTONE AND FERTILIZERS TO PERMANENT HAYLAND[1]

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ABSTRACT

Limestone, nitrogen, phosphorus and potassium, alone and in various combinations, were applied to the surface of permanent hayland during a 27-year period. Both limestone and phosphorus produced marked changes in the chemical properties of the soil. Phosphorus content of the soil where surface applications of this fertilizer were made decreased markedly with depth of sampling. Yield response to phosphorus was greater than to nitrogen or potassium although changes in botanical composition of the sward indicated the value of nitrogen for grass and of limestone for legumes. Irrespective of the treatment, yields declined with time.

INTRODUCTION

Surface application of limestone and fertilizer to hay and pasture sods is a widespread practice in the Atlantic Provinces. At one time the majority of the fertilizers used were applied to the hoed or cultivated crops in the rotation and succeeding hay crops had to depend almost entirely on residual fertilizer. In recent years, however, increased emphasis on grassland farming has focused attention on the fertility requirements of hay and pasture crops.

An experiment designed to evaluate the effects of top dressing hay fields with various fertilizers and limestone has been in progress at the Experimental Farm, Nappan, Nova Scotia, for 27 years. Results obtained during the first 7 years have been published (3). Although there have been some treatment changes and the application rates may differ from those now recommended, the long-term trends in fertility levels, yields, and botanical composition are of considerable interest and importance. These are presented in this paper.

MATERIALS AND METHODS

The experiment was initiated in 1931. It consisted of 36 plots of 1/100-acre each and was located on established hayland. The soil of the experimental area, which was last ploughed and seeded with a nurse crop in 1923, is classified as Nappan clay loam (5). There is no record of the area having received manure or commercial fertilizer from 1914 until the start of the experiment.

Fertilizer and dolomitic limestone treatments, as shown in Table 1, were applied on the sod in the spring. There were two replicates of each treatment arranged in a randomized block design.

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TABLE 1.—TREATMENTS APPLIED ON THE SOD OF PERMANENT HAY PLOTS

Treatment identification[1]	Treatment
C	Check—no fertilizer 1931-57.
C_1	Check 1931-42. NH_4NO_3 125 lb./ac. and sulphur 50 lb./ac. annually 1943-57.
N	$NaNO_3$ 250 lb./ac. annually 1931-45. NH_4NO_3 125 lb./ac. annually 1946-57.
SA	$(NH_4)_2SO_4$ 194 lb./ac. annually 1931-57.
NC	Nitrochalk 250 lb./ac. annually 1931-42. NH_4NO_3 125 lb./ac. and sulphur 50 lb./ac. annually 1943-57.
P	Superphosphate (16%) 500 lb./ac. 1931, '32 and '36. Superphosphate (20%) 400 lb./ac. 1940, '44, '48, '52, and '55.
K	KCl (48%) 100 lb./ac. 1931, '32, '36, '40, and '44. KCl (60%) 100 lb./ac. 1948, '52, and '55.
L	Dolomitic limestone 2 tons/ac. 1931, '32, '36, '40, '52, and '55.
NL	Combination of treatment N and 2 tons/ac. dolomitic limestone in 1931, '36, '40, and '56.
PL	Combination of treatment P and 2 tons/ac. dolomitic limestone in 1931, '36, '40, and '56.
KL	Combination of treatment K and 2 tons/ac. dolomitic limestone in 1931, '36, '40, and '56.
NP	Combination of treatments N and P.
NK	Combination of treatments N and K.
PK	Combination of treatments P and K.
NPK	Combination of treatments N, P, and K.
NPKL	Combination of treatments N, P, and K and 2 tons/ac. dolomitic limestone in 1931, '36, '40, and '56.

[1]Experiment included 6 plots of treatment C and 2 plots of all other treatments.

Composite soil samples of 15 borings each and representative of the 0-1, 1-2, 2-3 and 3-6 inch depths were taken from all plots in the fall of 1956. The following year comparable samples representative of the 6-12, 12-18, 18-24 and 24-30 inch depths were taken from the six checks and all limed plots.

The pH of all samples were determined with a glass electrode using a 1:1 soil-water ratio. The soil samples taken in 1956 were analysed for adsorbed and easily acid-soluble phosphorus (1) and for exchangeable potassium (6). Treatment differences were determined by means of a *t* test (4).

Crop yields were determined by weighing all forage from each plot, and removing representative sub-samples for dry matter determinations. A botanical survey (3) was made in 1937 and in 1956 species foliage cover was estimated by using a 0.04-sq.m. frame and taking 10 readings per plot.

RESULTS

The effects of various treatments on the chemical properties of soil, on crop yields, and on botanical composition were evaluated by grouping data from plots which received nitrogen, phosphorus, potassium or limestone and comparing them with data from comparable plots which did not receive nitrogen, phosphorus, potassium or limestone.

Effect of Treatments on Chemical Properties of the Soil

Differences in pH resulting from surface application of limestone are shown in Table 2. At any one sampling depth, differences between the checks and plots receiving various fertilizers but no limestone were not

TABLE 2.—EFFECT OF SURFACE APPLICATIONS OF LIMESTONE ON SOIL REACTION

Treatment identification	No. of plots	Soil pH values							
		0-1 in.		1-2 in.		2-3 in.		3-6 in.	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Check	6	5.5	±0.23	5.5	±0.25	5.5	±0.24	5.5	±0.24
N, P, K, NPK	8	5.5	±0.21	5.6	±0.21	5.7	±0.20	5.7	±0.18
NL, PL, KL, NPKL	8[1]	6.6	±0.08	6.2	±0.08	6.1	±0.10	6.1	±0.11
L	2[2]	7.1		7.1		6.9		6.7	

[1]All plots received 8 tons/ac. of limestone 1931-57.
[2]All plots received 12 tons/ac. of limestone 1931-57.

TABLE 3.—EFFECT OF SURFACE APPLICATIONS OF SUPERPHOSPHATE ON THE ADSORBED AND EASILY ACID-SOLUBLE PHOSPHORUS CONTENT OF SOIL

Treatment identification	No. of plots	Adsorbed and easily acid-soluble phosphorus—p.p.m. air dry basis							
		0-1 in.		1-2 in.		2-3 in.		3-6 in.	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Check	6	14.7	±1.8	9.0	±1.3	8.0	±1.6	6.3	±1.7
N, K, NK	6	9.6	±2.3	8.5	±2.1	6.3	±1.0	6.3	±1.2
NP, PK, NPK	6	39.8	±9.2	25.1	±6.0	19.3	±3.6	11.1	±2.6

TABLE 4.—EFFECT OF SURFACE APPLICATIONS OF MURIATE OF POTASH ON THE EXCHANGEABLE POTASSIUM CONTENT OF SOIL

Treatment identification	No. of plots	Exchangeable potassium(K) in m.e./100 grams air dry soil					
		0-1 in.		1-2 in.		3-6 in.	
		Mean	SE	Mean	SE	Mean	SE
Check	6	0.41	±0.05	0.30	±0.06	0.17	±0.01
N. P. NP	6	0.33	±0.03	0.27	±0.02	0.15	±0.01
NK, PK, NPK	6	0.38	±0.05	0.27	±0.01	0.16	±0.01

significant. In plots which received a total of 8 tons per acre of limestone together with various fertilizers, reaction in the surface inch was significantly higher than at any of the other three depths. However, at any one depth the pH values of these plots were significantly higher than the checks and plots receiving no limestone.

As would be expected the greatest reduction in soil acidity occurred in the two plots where a total of 12 tons per acre of limestone was applied. Samples taken below 6 inches showed that limestone applications had influenced soil reaction to at least the 24-30 inch depth. At this depth the mean pH values for the checks and plots receiving the low and high rate of limestone were 5.4, 5.9, and 6.1 respectively.

The adsorbed and easily acid-soluble phosphorus content of the check plots and of plots which did and did not receive surface applications of superphosphate is shown in Table 3. Differences between the checks and plots receiving no phosphorus were not significant. However, except at the 3-6 inch depth, phosphorus levels in plots where superphosphate was applied were significantly higher than in the checks or the no-phosphorus plots. A comparison of values for no-phosphorus and phosphorus plots shows that the effect of surface applications of superphosphate decreased markedly with increasing depth.

Results presented in Table 4 indicate that the exchangeable potassium content of the soil was not changed by applications of muriate of potash. At any one depth there were no significant differences between the checks and no-potassium plots, the checks and plots receiving potassium, or the no-potassium and potassium plots.

Yield Data

Yields obtained with different treatments are presented in Table 5. The plots which received a complete fertilizer, either with or without limestone, gave the highest yields and the treatments which included phosphorus, either alone or in combination, were superior to all others. While yield differences were not large, ammonium sulphate (SA) gave better yield responses than sodium nitrate or ammonium nitrate. Neither muriate of potash nor limestone were beneficial when applied alone. It has been shown, however, that on certain of the lighter textured soil types in the province, where the sod is not very dense, the surface application of lime accompanied by adequate fertilization has increased the yield of hay and pasture significantly (2).

In Table 6 yields are shown for plots where the effects of nitrogen, phosphorus, potassium or limestone treatments could be evaluated. Although yields declined with advancing years irrespective of the treatments applied, the data show that phosphorus was relatively more important than nitrogen, potassium or limestone.

Botanical Composition

Botanical composition was evaluated by species foliage cover determinations made on the plots in the fall of the year after removal of the hay crop. Information obtained was representative of the per cent ground area covered by grass, clover, and weeds. This information was not necessarily representative of the per cent species contribution to herbage cut and used for yield values since many of the weeds were low growing species not harvested with a mowing machine. Consequently, the contribution of weeds to the reported yields was lower, and that of agronomic species higher than indicated by cover data.

Data presented in Table 7 show the effects of nitrogen, phosphorus, potassium and limestone treatments on botanical composition of the sward. Orchard grass and timothy were combined under grass and red and white clover under clover. All other growth was grouped under weeds. A comparison of the nitrogen and no-nitrogen plots, as well as the phosphorus and no-phosphorus plots, shows the value of these two nutrients in the maintenance of grass although the difference between the potassium and no-

TABLE 5.—EFFECT OF DIFFERENT TREATMENTS ON AVERAGE YIELDS OF PERMANENT HAY PLOTS

Period	Hay yields—tons dry matter per acre													
	NPK	NPKL	NP	PK	PL	P	SA	KL	NL	NK	N	C	K	L
1931–37	2.44[1]	2.49	2.24	1.88	1.84	1.55	1.49	1.43	1.29	1.26	1.18	1.12	1.16	1.02
1951–57	1.64	1.43	1.34	1.40	1.28	1.20	1.11	0.81	1.00	0.78	0.98	0.64	0.48	0.43
1931–57	2.02	1.96	1.73	1.61	1.44	1.36	1.22	1.02	1.00	0.94	0.94	0.82	0.78	0.64

[1]Figures for all treatments are averages of 2 plots except C which is the average of 6 plots.

TABLE 6.—PERMANENT HAY PLOT YIELDS GROUPED TO SHOW EFFECT OF NITROGEN, PHOSPHORUS, POTASSIUM OR LIMESTONE

Treatment identification		No. of plots	Average yields in tons per acre of dry matter				
			1931–37	1938–44	1945–51	1952–57	1931–57
Check		6	1.12	0.87	0.62	0.62	0.82
No nitrogen	P, K, PK	6	1.53	1.34	1.09	1.01	1.25
Nitrogen	NP, NK, NPK	6	1.98	1.67	1.34	1.16	1.56
No phosphorus	N, K, NK	6	1.20	0.87	0.73	0.72	0.89
Phosphorus	NP, PK, NPK	6	2.19	1.95	1.54	1.37	1.79
No potassium	N, P, NP	6	1.66	1.38	1.19	1.07	1.34
Potassium	NK, PK, NPK	6	1.86	1.64	1.31	1.26	1.52
No limestone	N, P, K, NPK	8	1.58	1.37	1.07	1.06	1.28
Limestone[1]	NL, PL, KL, NPKL	8	1.76	1.41	1.09	1.12	1.36
Limestone alone[2]	L	2	1.02	0.68	0.41	0.44	0.64

[1]Total of 8 tons/ac. 1931-57 [2]Total of 12 tons/ac. 1931-57

TABLE 7.—EFFECT OF SURFACE APPLICATIONS OF FERTILIZER AND LIMESTONE ON BOTANICAL COMPOSITION OF PERMANENT HAY PLOTS

Treatment identification		No. of plots	Sward population—per cent cover					
			Grass		Clover		Weeds	
			1937	1956	1937	1956	1937	1956
			%	%	%	%	%	%
Check		6	9.1	1.8	9.5	6.0	81.4	92.2
No nitrogen	P, K, PK	6	13.5	8.3	9.7	9.2	76.8	82.5
Nitrogen	NP, NK, NPK	6	22.2	25.2	5.5	3.3	72.3	71.5
No phosphorus	N, K, NK	6	7.9	12.3	7.2	4.1	84.9	83.6
Phosphorus	NP, PK, NPK	6	26.2	20.4	6.5	5.0	67.3	74.6
No potassium	N, P, NP	6	10.0	17.3	8.2	4.5	81.8	78.2
Potassium	NK, PK, NPK	6	25.3	19.1	6.5	4.7	68.2	76.2
No limestone	N, P, K, NPK	8	13.3	15.0	7.9	6.1	78.8	78.9
Limestone[1]	NL, PL, KL, NPKL	8	19.6	16.2	10.0	14.8	70.4	69.0
Limestone alone[2]	L	2	7.5	12.6	9.5	8.2	83.0	79.2

[1]Total of 8 tons/ac. 1931-57 [2]Total of 12 tons/ac. 1931-57

potassium plots, while marked in 1937, was not evident in 1956. The data also show that clover responded to limestone applied with other plant nutrients but was depressed by nitrogen.

Between 1937 and 1956 there was a marked increase in per cent cover of low sweet blueberry and wild strawberry in the check plots. This may have been due to lack of competition from grasses and clovers which require higher nutrient levels to dominate the sward.

DISCUSSION

Surface applications of either limestone or superphosphate were accompanied by marked changes in the chemical properties of the soil. The analytical results, however, indicated downward movement of superphosphate to be considerably less than that of limestone.

Yield data, presented in Tables 5 and 6, show that of all treatments applied the most beneficial were those containing phosphorus. The information on botanical composition of the sward substantiated this. Data in Table 7 show that applications of nitrogenous fertilizer promote the growth of grass, suppress the growth of clover, and that applications of limestone and major plant nutrients were more beneficial to clover than to grass.

The progressive decrease in hay yields, irrespective of treatments applied, may be attributed primarily to inadequate fertility for satisfactory maintenance of agronomic species. Thus the need is indicated for periodic ploughing and reseeding, at least of acid soils of low fertility, and also for liming and fertilization. Results from other experiments*, in which fertilizer was applied at higher rates, have suggested that yields decline on land left in sod for long periods and that more favourable yield levels may be maintained through reseeding at intervals of no longer than 5 or 6 years.

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REFERENCES

1. Bray, R. H. Correlation of soil tests with crop response to added fertilizers and with fertilizer requirement. Diagnostic techniques for soils and crops, pp. 58-86. American Potash Institute, Washington, D.C. 1948.
2. Calder, F. W., and F. S. Warren. Pasture renovation in the Maritime Provinces. Can. Dept. Agr. Publ. 1024. 1958.
3. Hilton, S. A., and C. D. T. Cameron. Renovation of old meadows without reseeding. Sci. Agr. 19:322-329. 1939.
4. Paterson, D. D. Statistical technique in agricultural research. McGraw-Hill Book Co., Inc., New York, N.Y. 1939.
5. Whiteside, G. B., R. E. Wicklund, and G. R. Smith. Soil survey of Cumberland County. Rept. 2, Nova Scotia Soil Survey. Truro, N.S. 1945.
6. Wright, L. E., *et al.* Chemical methods of soil analysis. Chem. Div., Science Service, Can. Dept. Agr., Ottawa. 1949.

*Unpublished data, Experimental Farm, Nappan, N.S.

EFFECT OF DRYING ON EXCHANGEABLE POTASSIUM OF ONTARIO SOILS AND THE RELATION OF EXCHANGEABLE POTASSIUM TO CROP YIELD[1]

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ABSTRACT

Exchangeable potassium in field moist, air-dry and oven-dry samples of surface soil of 15 soil types was extracted with 0.1 N ammonium acetate. It was found that, if the per cent potassium saturation of the cation exchange capacity was 1.11 ± 0.12, no change in the amount of exchangeable potassium occurred during drying of the soil. Above this equilibrium per cent potassium saturation, the exchangeable potassium was decreased by drying, and below this per cent saturation exchangeable potassium was increased by drying.

The degree of correlation of exchangeable potassium at each of the different soil moisture contents with yields, i.e. Log (100 − % yield), of wheat, oats, and corn in the field was not affected by the drying treatment. Moreover, the exchangeable potassium level accounted for a relatively small part of the yield variability of these crops. For potatoes, however, there was a highly significant correlation between exchangeable potassium at each soil moisture content and yield, i.e. Log (100 − % yield) and the correlation coefficient was highest for the oven-dried soil.

The degree of correlation between per cent potassium saturation at the different soil moisture contents with crop yield was not significant for any of the four crops.

INTRODUCTION

Air drying or oven-drying may cause an increase or decrease in the exchangeable potassium level of soil. Wood and De Turk (10) and Attoe and Truog (2) on air-drying of fertilized soils found that fixation of exchangeable potassium occurred in all instances. In contrast to this, Luebs, Stanford and Scott (6) found that potassium was released on drying of 13 soils tested. Reitemeier, Brown, and Holmes (9) found that some, but not all, soils increased in exchangeable potassium on air-drying. McEwen and Matthews (8) showed that oven-drying of soil resulted in an increase or a decrease in exchangeable potassium depending on the level of exchangeable potassium established in the soil sample before oven-drying. This result supported the suggestion of Bray and De Turk (4) that each soil has a natural equilibrium level of exchangeable potassium.

McEwen and Matthews (8) found that oven-drying of soil caused a change in the exchangeable potassium level toward the equilibrium level and that the exchangeable potassium measured in oven-dry soil was closely correlated with the potassium-supplying power of the soil. They suggested that exchangeable potassium level after oven-drying may give highest correlation with crop yields and, therefore, may be most useful in predicting potassium fertilizer requirement.

The objectives of this study were; (a) to determine the equilibrium exchangeable potassium levels of several Ontario soils; (b) to establish the relation of exchangeable potassium level and per cent potassium

[1]Contribution from Department of Soils, Ontario Agricultural College, Guelph, Ont. The financial assistance of the American Potash Institute in part of this study is gratefully acknowledged.

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saturation of the cation exchange capacity of soil to the amount of release or fixation of exchangeable potassium upon drying; and (c) to show the degree of correlation between yield response of wheat, oats, corn, and potatoes to potassium fertilizer in the field and the exchangeable potassium in moist, air-dry and oven-dry soil samples from the respective field plots.

MATERIALS AND METHODS

Laboratory Analyses

Forty-eight samples, originally derived from a bulk sample of Fox sandy loam, were obtained from a continuous cropping study previously conducted in the greenhouse (8). These samples differed in level of exchangeable potassium as a result of fertilizer treatment during the continuous cropping period. Similar samples of Guelph loam and Haldimand clay were also used.

In addition, 18 surface samples that differed in level of exchangeable potassium as a result of different fertilizer application and cropping were collected from each of 12 soil types in central and southwestern Ontario. These soil types were included in the field correlation study described below.

One portion of each of the 360 soil samples was air-dried under controlled humidity so that the moisture content was 2 to 5 per cent. A second portion was oven-dried at 105° C. for 24 hours. The remainder of each sample was maintained at field moisture content.

The exchangeable potassium content of each sample at each moisture content was determined by extracting 25 gm. of soil (oven-dry basis) with 250 ml. of neutral 0.1 N ammonium acetate. The amount of potassium extracted by this method has been found in this laboratory to be the same as that extracted by neutral normal ammonium acetate. Potassium was determined in the extract with a Baird flame photometer using lithium as an internal standard. The cation exchange capacity of each air-dry sample was determined by the neutral normal ammonium acetate method with extraction of adsorbed ammonia before distillation (1).

Field Correlations

In order to correlate the exchangeable potassium in several soils in the moist, air-dry, and oven-dry state with yield of crops, yield data were obtained on six locations for wheat, six for oats, six for corn, and three for potatoes. The field plot design which was established on privately-owned farms consisted of two plots, one receiving no potassium and the other receiving sufficient potassium fertilizer so that crop yield was not limited by a deficiency of potassium. These paired plots were replicated six times on each location for wheat, oats, and corn and three times for potatoes. All plots received nitrogen and phosphorus at the rates indicated in Table 1.

The yield of the no-potassium plot (NP) was expressed as a percentage of the yield of the adjacent plot that received potassium fertilizer (NPK). The soil test value of a soil sample taken from the no-potassium plot before the crop was planted was related to this percentage yield (y) by the modified Mitscherlich equation below:

$$\text{Log } (100\text{-}y) = \text{Log } 100\text{-}c_1b$$

where the yield of the fully fertilized (NPK) plot = 100, y = yield of NP plot expressed as a percentage of the yield of NPK plot, b = amount of exchangeable potassium in the surface soil according to soil test and, c_1 = a proportionality constant.

A sample of the surface soil from each no-potassium (NP) plot was obtained by taking ten borings with a soil sampling tube. Each sample was thoroughly mixed and portions of each were subjected to drying treatments and the exchangeable potassium of the moist, air-dry, and oven-dry portions was determined as described above.

Although six replications were established for wheat, oats, and corn and three for potatoes on each location, only those plots that gave a yield of less than 95 per cent of the adjacent NPK plot were included in the statistical correlation. The number of such plots for each crop is indicated as number of comparisons in Table 1. The c_1 values were calculated separately for each replicate on each location.

TABLE 1.—CROPS, FERTILIZER TREATMENTS, AND NUMBER OF COMPARISONS INCLUDED IN CORRELATION STUDY

Crop	Fertilizer Treatment			No. of Comparisons
	N*	P_2O_5*	K_2O**	
	lb./ac.	lb./ac.	lb./ac.	
Wheat	50	120	120	16
Oats	20	40	100	29
Corn	120	80	200	26
Potatoes	100	200	200	9

*Applied to all plots
**Applied to fully treated plots only

RESULTS AND DISCUSSION

The laboratory results show that the exchangeable potassium of the moist soil samples from the greenhouse and field was markedly changed by air-drying and oven-drying. For each of the 15 soil types studied, some samples showed an increase while others showed a decrease in exchangeable potassium upon being dried. Data in Table 2 for three samples of each of four soil types illustrate that for a given soil type, if the exchangeable potassium in the moist soil was relatively low, exchangeable potassium increased upon drying and vice versa.

In order to establish the equilibrium level of exchangeable potassium for each soil type, the regression of exchangeable potassium measured in the oven-dry soil sample on that measured in the moist sample was calculated. The regression lines and equations for two of the soils, Fox sandy loam and Haldimand clay, are shown in Figure 1. From the regression equation the value of X when X = Y, i.e. at the equilibrium point, was calculated and is indicated in Figure 1 as being 112 pounds of K_2O per acre for Fox sandy loam and 335 pound per acre for Haldimand clay. Similarly the equilibrium exchangeable potassium level, i.e. the level at which drying

TABLE 2.—EXCHANGEABLE POTASSIUM CONTENT OF SEVERAL SOIL SAMPLES IN MOIST, AIR-DRY AND OVEN-DRY STATE

Soil type	Sample No.	K Saturation (Moist soil)	Exchangeable K_2O lb/ac.*		
			Moist	Air-dry	Oven-dry
		%			
Guelph loam	64	0.93	140	156	174
	113	1.06	185	162	185
	97	1.48	251	163	184
London loam	96	0.70	130	180	183
	52	0.93	197	221	223
	17	1.10	206	198	196
Perth silt loam	82	0.48	152	280	293
	9	1.11	237	234	222
	117	2.24	458	301	284
Beverly silty clay loam	83	1.13	187	181	183
	43	1.93	277	205	173
	9	2.36	399	294	212

*On oven-dry basis

TABLE 3.—MEAN CATION EXCHANGE CAPACITY, EQUILIBRIUM EXCHANGEABLE POTASSIUM AND PER CENT POTASSIUM SATURATION OF SOILS

Soil type	Cation exchange capacity*	Equilibrium value	
		Exchangeable K_2O**	K Saturation
	m.e./100 gm.	lb./ac.	%
Tioga loamy sand	8.9	115	1.35
Fox sandy loam	10.1	112	1.19
Guelph loam	12.4	164	1.25
Honeywood loam	13.8	152	1.10
Guelph loam	15.1	137	0.97
London loam	23.3	338	1.17
Perth silt loam	27.3	318	1.10
Beverly silt loam	22.3	279	1.18
Kemble silt loam	24.4	249	0.96
Honeywood silt loam	17.4	201	1.09
Beverly silty clay loam	17.1	195	1.08
Huron clay loam	20.2	203	1.07
Perth clay loam	20.3	185	0.86
Saugeen clay loam	23.1	338	1.17
Haldimand clay	30.3	335	1.18
Mean			1.11 ± 0.12

*Average of 18 samples for each soil type
**Calculated from regression equation based on 18 samples of each soil type

causes neither an increase nor decrease in exchangeable potassium, was calculated for the 15 soils studied and is reported in Table 3. In general there was an increase in equilibrium exchangeable potassium content with increasing clay content of the soil and increasing cation exchange capacity.

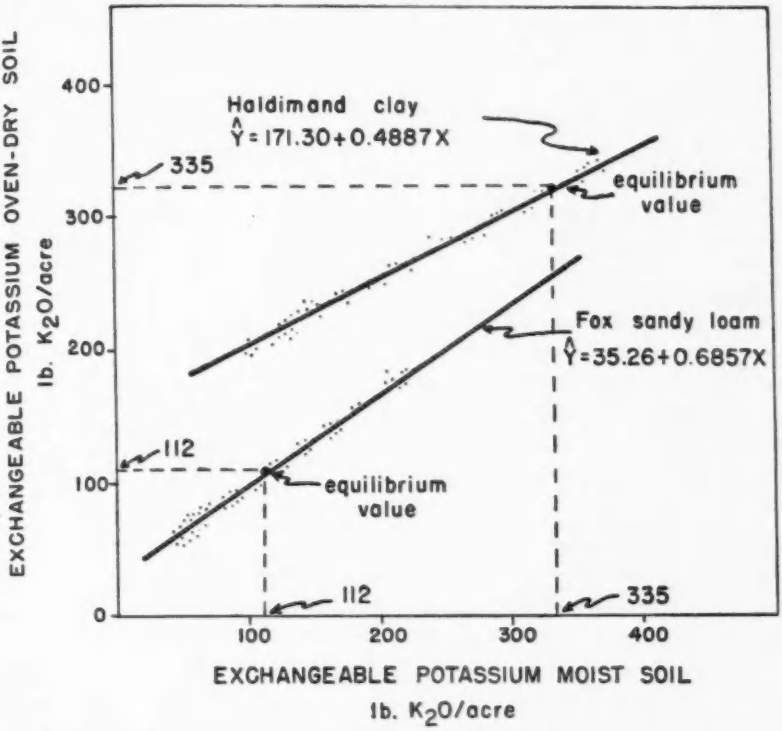

FIGURE 1. Relation between exchangeable potassium of oven-dry soil and exchangeable potassium of moist soil. [After McEwen (7)].

If it is true that the fixation of exchangeable potassium upon drying of the soil occurs by the trapping of potassium ions between the layers of clay minerals, fixation might be expected to increase as the number of exchangeable potassium ions was increased relative to the number of other exchangeable cations in the soil. On the other hand, there is apparently a mechanism for release of potassium to exchangeable form upon drying. Indeed, the rate of release exceeds the rate of fixation at exchangeable potassium levels that are less than the equilibrium value. The actual amount of exchangeable potassium necessary in a soil before fixation occurred upon drying varied widely among soils but was highly correlated with the cation exchange capacity, r = 0.97**. Hence the per cent potassium saturation at equilibrium was found to be relatively constant among the soils studied, the average being 1.11 $\pm$ 0.12 per cent potassium saturation as reported in Table 3. It was concluded, therefore, that, regardless of soil type, release of potassium to exchangeable form was likely to occur upon drying the soil if the per cent potassium saturation was less than 1.11 and fixation was likely to occur if the per cent potassium saturation was greater than 1.11.

TABLE 4.—CORRELATION OF POTASSIUM SOIL TEST VALUES WITH PERCENTAGE YIELD OF CROPS IN 1958 AND MEAN c_1 VALUES FOR EACH CROP

Crop	Moisture content of soil	Coefficient of correlation (r)	c_1 Values	
			Mean	Coefficient of variation (V)
				%
Wheat	Moist	−0.39	.00428	37.38
	Air-dry	−0.38	.00474	44.09
	Oven-dry	−0.43*	.00448	44.42
Oats	Moist	−0.24	.00483	62.32
	Air-dry	−0.29	.00454	45.37
	Oven-dry	−0.26	.00468	41.45
Corn	Moist	−0.13	.00327	37.00
	Air-dry	−0.12	.00308	37.66
	Oven-dry	−0.17	.00312	42.31
Potatoes	Moist	−0.71**	.00407	28.01
	Air-dry	−0.77**	.00376	23.96
	Oven-dry	−0.81**	.00459	22.66

*Significant at 5% level
**Significant at 1% level

CORRELATION OF EXCHANGEABLE POTASSIUM IN MOIST, AIR-DRY AND OVEN-DRY SOIL WITH PERCENTAGE YIELD OF CROPS

Because drying of the soil before extraction of exchangeable potassium may have a marked effect on the result as indicated in Table 2, it was necessary to determine which drying treatment gave results that correlated to the greatest degree with crop yields in the field. The range in percentage yield obtained in the field experiments was 60 to 95 per cent for wheat, 70 to 95 per cent for oats, 61 to 95 per cent for corn, and 64 to 94 per cent for potatoes.

The correlation coefficients relating Log (100-y) of the Mitscherlich equation with soil test value, b, measured after each drying treatment are reported in Table 4. There was no significant correlation for oats and corn and only the exchangeable potassium of the oven-dry samples showed significant correlation with Log (100-y) for wheat. For potatoes, however, there was a highly significant correlation at each moisture content between exchangeable potassium and Log (100-y). This high correlation for potatoes is probably due to the fact that all of the soils on which the potatoes were grown were of medium to coarse texture. Barber (3) has shown that in coarse textured soils the exchangeable potassium level accounted for a larger proportion of the crop yield variability than it did in fine textured soils.

The mean c_1 values and their coefficients of variability are also shown in Table 4. Although the c_1 values for a given crop were remarkably similar for the three soil moisture contents, the coefficients of variability of c_1 values for wheat, oats and corn were relatively large for all drying treatments.

TABLE 5.—COEFFICIENTS OF CORRELATION OF LOG (100 — % YIELD) WITH PER CENT POTASSIUM SATURATION AT THREE SOIL MOISTURE LEVELS

Crop	Coefficient of correlation of Log (100-y) with per cent potassium saturation		
	Moist soil	Air-dry soil	Oven-dry soil
Wheat	−0.17	−0.34	−0.22
Oats	+0.32	+0.43	+0.42
Corn	−0.02	−0.07	−0.06
Potatoes	−0.29	−0.29	−0.18

The per cent potassium saturation of the soil at each of the three moisture contents was correlated with Log (100-y) and the coefficients are shown in Table 5. In no instance was there a significant correlation. Halstead and Heeney (5) however have recently reported a significant correlation between per cent potassium saturation of sandy loam soils and Log (100-y) of tomatoes.

It was concluded that the exchangeable potassium as measured by extraction with 0.1 N ammonium acetate following any of the drying treatments did not account for a satisfactory portion of the variability in yields of wheat, oats, and corn in 1958. Moreover, expression of the potassium level as per cent saturation of the exchange capacity of the soils did not improve the correlation.

Correlations of exchangeable potassium in air-dry soils with Log (100-y) for the same crops in 1955, 1956, and 1957 have given results similar to those reported here for 1958. It is apparent that the exchangeable potassium level in the soil is not a reliable measure, in itself, of the potassium sufficiency of the soil for the crops studied except potatoes.

REFERENCES

1. Atkinson, H. J., G. R. Giles, A. J. MacLean, and J. R. Wright. Chemical methods of soil analysis. Contribution No. 169, rev. Chem. Div., Science Service, Canada Dept. Agr., Ottawa. 1958.
2. Attoe, O. J., and E. Truog. Exchangeable and acid-soluble potassium as regards availability and reciprocal relationships. Soil Sci. Soc. Amer. Proc. 10:81–86. 1945.
3. Barber, T. E. Measurement of the release of certain cations by some Ontario soils. M.S.A. thesis, University of Toronto. 1959.
4. Bray, R. H., and E. E. De Turk. The release of potassium from non-exchangeable forms in Illinois soils. Soil Sci. Soc. Amer. Proc. 3:101–106. 1938.
5. Halstead, R. L., and H. B. Heeney. Exchangeable and water-soluble potassium in soils and degree of saturation in relation to tomato yields. Can. J. Soil Sci. 39: 129–135. 1959.
6. Luebs, R. E., G. Stanford, and A. D. Scott. Relation of available potassium to soil moisture. Soil Sci. Soc. Amer. Proc. 20:45–50. 1956.
7. McEwen, H. B. Measurement of exchangeable potassium and potassium-supplying power of soils. M.S.A. thesis, University of Toronto. 1957.
8. McEwen, H. B., and B. C. Matthews. Rate of release of non-exchangeable potassium by Ontario soils in relation to natural soil characteristics and management practices. Can. J. Soil Sci. 38:36–43. 1958.
9. Reitemeier, R. F., I. C. Brown, and R. S. Holmes. Release of native and fixed non-exchangeable potassium of soils containing hydrous mica. U.S. Dept. Agr. Tech. Bull. 1049. 1951.
10. Wood, L. K., and E. E. De Turk. The release of fixed potassium to replaceable or water-soluble forms. Soil Sci. Soc. Amer. Proc. 7:148–153. 1942.

THE NUTRIENT COMPOSITION OF HYBRID CORN AS INFLUENCED BY FERTILIZATION

I. THE NITROGEN PERCENTAGE IN LEAF AND GRAIN[1]

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ABSTRACT

In field experiments on a sandy loam and a clay soil in 2 consecutive years, the yield of grain and percentage of nitrogen in ear shoot leaf and in the grain increased with increasing rates of nitrogen fertilization. The change in nitrogen percentage was greater for the leaf than for the grain and correlation between yield and nitrogen content was better for leaf samples than for grain samples. The relation between nitrogen content for the ear shoot leaf and yield was a straight line when rate of nitrogen fertilization was the only nutrient variable influencing yield. Thus, in this case, there was no evidence of luxury consumption or a critical level of nitrogen. However, when yield was limited by lack of phosphorus, luxury consumption of nitrogen did occur. The influence of applied nitrogen fertilizer on leaf nitrogen percentage was greater on the sandy loam than on the clay in spite of the fact that nitrogen percentage of the ear shoot leaf from the unfertilized plots was similar.

INTRODUCTION

When application of a fertilizer nutrient increases the amount of plant material produced, there is usually a corresponding increase in the total amount of the nutrient absorbed by the plant. Increased total absorption may be achieved whether the per cent composition remains constant, increases, or even decreases. Moreover, total uptake of a nutrient may also increase with an increase in per cent composition while yield remains constant. This latter phenomenon is commonly referred to as "luxury consumption" and suggests storage of a nutrient in a non-assimilated form or some form bearing no relation to yield. The minimum nutrient content at which luxury consumption becomes operative represents the "critical percentage" of that nutrient.

A number of workers, (1, 3, 5, 7, 8) have recently reported that application of fertilizer nitrogen increases the per cent nitrogen in corn leaf and grain tissue but there is some disagreement as to the nature of the relation between applied nitrogen, nitrogen content and yield. Although Tyner (7) showed the regression of yield on leaf nitrogen percentage to be linear, he stated his data suggested a break in the curve which gave rise to tentative calculation of a critical leaf nitrogen percentage of 2.90 per cent. Viets *et al.* (8), Bennett *et al.* (3), and Andharia *et al.* (1) report the relationship between leaf nitrogen percentage and yield to be linear with no evidence of a departure from linearity or a flex point that could be termed the critical percentage. Krantz and Chandler (5) reported that leaf and grain nitrogen was increased by applications of nitrogen fertilizer. Most workers report a correlation between leaf nitrogen and grain nitrogen but the magnitude of change with fertilization is greater in the leaf and, therefore, leaf samples have generally been preferred to grain samples.

[1]Contribution No. 6, from the Research Station, Research Branch, Canada Department of Agriculture, Harrow, Ont.

Because nitrogen fertilization has produced spectacular increases in corn yield in southwestern Ontario and the "critical percentage" concept could be a useful tool in surveying the adequacy of nitrogen fertilization, the authors felt that a study of tissue nitrogen content and corn yields taken from established fertility projects was warranted. The primary purpose was to establish the existence of a "critical nitrogen percentage" for corn grown in southwestern Ontario and, if such a value existed, to study the effect of the two widely different soil textures characteristic of the district on the "critical percentage". In addition, the study might shed some light on the controversy existing in the literature.

MATERIALS AND METHODS

Fertility plots were established on Brady sandy loam and Brookston clay (6) in 1957 and 1958 using the following treatments expressed in pounds of nutrient per acre:

Rates of nitrogen experiment			Rates of P_2O_5 experiment			Rates of K_2O experiment		
Pounds per acre			Pounds per acre			Pounds per acre		
N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
0	120	120	120	0	120	120	120	40
40	120	120	120	40	120	120	120	40
80	120	120	120	80	120	120	120	80
120	120	120	120	120	120	120	120	120

In 1957 the variable nutrient was applied by 1), broadcasting on ploughed land followed by disking, and 2), banding along the row about 2 inches to the side and 1 inch below the seed; but in 1958 at the Brady location only the latter method was used. In all cases the nutrient sources were ammonium nitrate, superphosphate and muriate of potash. The nutrients applied in blanket treatment were broadcast in each case. Except for the 1958 Brady location, which was a randomized block, the experimental design was a split plot with four replications and with method of application as sub-plot treatments. Sub-plots were 40 feet in length and contained four rows of corn. The two centre rows were harvested and yield was expressed as bushels of shelled corn at 15.5 per cent moisture in the grain. A medium maturity hybrid, for this area, Pioneer 349, was used.

Ten ear shoot leaves were collected from each plot during the silking period. In 1957, leaf samples were collected from the Brady soil location during early silking and from the Brookston soil at late silking. In 1958, samples were collected at each site when 50 per cent of the plants in each plot carried silks. Grain samples were collected at harvest in 1957 only.

Kjeldahl nitrogen was determined by the A.O.A.C. (2.23) improved kjeldahl method for nitrate free samples (2). Nitrate nitrogen was considered negligible since by analyses it was found to represent less than 1 per cent of the total nitrogen in the leaf tissue.

TABLE 1.—YIELD OF SHELLED CORN (15.5 PER CENT MOISTURE) IN RELATION TO VARIOUS APPLICATIONS OF FERTILIZER

Fertilizer treatment	Brady sandy loam		Brookston clay	
	1957	1958	1957	1958
lb./acre	bu./acre	bu./acre	bu./acre	bu./acre
0–120–120	43.9	38.2	55.0	47.8
40–120–120	68.1	64.5	71.3	66.0
80–120–120	76.9	80.4	86.8	68.7
120–120–120	82.4	89.0	94.0	76.4
L.S.D. P. 05	9.3	10.4	17.4	21.7
120– 0–120	74.0	82.3	88.8	52.1
120– 40–120	70.4	83.6	97.2	64.7
120– 80–120	77.7	84.2	102.5	72.2
120–120–120	73.7	81.4	102.3	69.5
L.S.D. P. 05	N.S.	N.S.	12.5	8.1
120–120– 0	81.6	91.1	90.0	87.2
120–120– 40	77.2	85.9	92.7	85.1
120–120– 80	81.2	87.1	93.1	86.7
120–120–120	83.6	91.1	92.7	83.3
L.S.D. P. 05	N.S.	N.S.	N.S.	N.S.

TABLE 2.—NITROGEN CONTENT OF EAR SHOOT LEAF OF CORN IN RELATION TO VARIOUS APPLICATIONS OF NITROGEN AND PHOSPHORUS

Fertilizer treatment	Brady sandy loam		Brookston clay	
	1957	1958	1957	1958
lb./acre	%	%	%	%
0–120–120	2.16	1.86	1.66	1.82
40–120–120	2.95	2.47	2.05	2.30
80–120–120	3.25	2.94	2.47	2.51
120–120–120	3.49	3.01	2.67	2.66
L.S.D. P. 05	0.34	0.24	0.37	0.11
120– 0–120	3.62	2.91	2.83	2.38
120– 40–120	3.57	2.83	2.92	2.44
120– 80–120	3.61	2.94	2.85	2.43
120–120–120	3.45	2.72	2.88	2.47
L.S.D. P. 05	N.S.	N.S.	N.S.	N.S.

EXPERIMENTAL RESULTS AND DISCUSSION

The change in yield effected by fertilizer treatment is shown in Table 1. Because method of application had little or no effect on yield average values are presented.

Application of nitrogen at 40 pounds per acre produced a marked increase in yield of grain on both soil types in each year, but the rate of increase diminished with further nitrogen increments. Yield increased

TABLE 3.—NITROGEN CONTENT OF CORN GRAIN IN RELATION TO VARIOUS APPLICATIONS OF NITROGEN AND PHOSPHORUS

Fertilizer treatment	Brady sandy loam 1957	Brookston clay 1957
lb./acre	%	%
0–120–120	1.34	1.27
40–120–120	1.44	1.33
80–120–120	1.69	1.50
120–120–120	1.72	1.59
L.S.D. P. 05	0.12	0.14
120– 0–120	1.90	1.71
120– 40–120	1.91	1.69
120– 80–120	1.86	1.69
120–120–120	1.90	1.70
L.S.D. P. 05	N.S.	N.S.

with the rate of phosphorus fertilization on the Brookston soil but not on the Brady. Potassium fertilization had no effect on yield on either soil type. From these data it may be concluded that the Brady soil was nitrogen deficient but phosphorus and potassium sufficient. The Brookston soil was nitrogen deficient at both locations, slightly phosphorus deficient at the 1957 location, increasingly phosphorus deficient at the 1958 location, and potassium was in good supply at both locations. These soil type characterizations assume significance in Part II of this paper,* concerned with the phosphorus composition.

Tables 2 and 3 report the per cent nitrogen in the ear shoot leaf and in the grain. Potassium fertilization had no effect on yield or nitrogen composition; therefore, the latter data are not presented here. The method of application had no consistent effect on composition so that average values are presented.

The pronounced change in nitrogen composition of the leaf with increased rates of nitrogen fertilization and its relationship to yield will be discussed more fully later. Although the rate of phosphorus application did affect grain yield on the Brookston soil in both years, nevertheless, the nitrogen content of the leaf was not changed. Total nitrogen absorbed has no doubt increased with the higher yields produced by the higher rates of phosphorus fertilization.

As was the case with the leaf tissue, nitrogenous fertilizer was the only one affecting the nitrogen composition of the grain on these two soils. The increase in nitrogen content of the ear shoot leaf amounted to 60 per cent, whereas the nitrogen content of the grain was increased by about 25 per cent. The difference is no doubt due to the fact that leaf nitrogen concentration reaches a maximum about mid-season, whereas accumulation in the grain continues to maturity (3, 4).

*At present in preparation, Research Station, Harrow, Ont.

TABLE 4.—CORRELATION AND REGRESSION COEFFICIENTS FOR YIELD VERSUS PER CENT NITROGEN

Variables	Soil type	Correlation coefficient*	Regression coefficient*
Yield on grain nitrogen	Brady 1957	0.724	66.36 ± 10.54
	Brookston 1957	0.792	86.39 ± 12.18
Yield on leaf nitrogen	Brady 1957	0.819	25.25 ± 3.24
	Brookston 1957	0.918	37.77 ± 2.99
	Brady 1958	0.807	34.27 ± 4.57
	Brookston 1958	0.660	33.23 ± 6.22

*All correlation and regression coefficients are statistically significant at the 1% level of probability.

THE RELATION OF YIELD TO NITROGEN COMPOSITION

The regression coefficients for the dependent variable, yield (Y) and the independent variable, nitrogen content (X), have been calculated. These are presented with their standard errors in Table 4.

The correlation and regression coefficients in Table 4 apply to the data from the rates of nitrogen experiments where nitrogen was the only nutrient variable influencing yield. Squaring the correlation coefficients in Table 4 shows that variation in leaf nitrogen in 1957 was associated with 67 per cent of the yield change on the Brady sandy loam and 65 per cent on the Brookston clay. The corresponding figures in 1958 were 85 and 44 per cent. The correlation coefficients calculated from the 1957 data show that variations in grain nitrogen account for less of the yield change than variations in leaf nitrogen. In addition the regression coefficients for yield on grain nitrogen are larger than those for yield on leaf nitrogen. Thus it is indicated that, for a given change in yield, there is a larger change in leaf nitrogen percentage than in grain nitrogen percentage. Accordingly predictions of nitrogen sufficiency based on grain nitrogen are subject to greater error than those based on leaf nitrogen. For these reasons the nitrogen content of the ear shoot leaf rather than that of the grain is preferable when determing the relation between nitrogen content and corn yield. This conclusion agrees with other workers (3, 5).

Because the following regression equations are linear and the data present no evidence of a departure from linearity or a flex point, it must be concluded that luxury consumption of nitrogen did not occur where nitrogen was the only nutrient variable influencing yield change. However, if the yield data (Table 1) for the rates of phosphorus experiment on the Brookston clay are compared with corresponding nitrogen percentages in Table 2 it is obvious that nitrogen content remains high throughout the range of yield obtained. Since leaf weight increased with the grain yield, the per cent leaf nitrogen can be considered proportional to the total nitrogen content of the leaf. Thus, it is concluded that luxury consumption did occur when yield was limited by lack of phosphorus. The slope of the regression lines of yield on leaf nitrogen was somewhat different for the two soils in the 1957 study, which suggests that the change in yield associated with a given change in nitrogen percentage was different for the two soils. Due to the fact that difference in physiological maturity at

sampling might have been a contributing factor, care was exercised in 1958 to ensure that all plots were sampled when 50 per cent of the plants carried silks. This technique produced lines with the same slope for both soil types in 1958. The position of the two lines was slightly different, so that the absolute yield value associated with a given nitrogen percentage was not identical.

$Y = -35.03 + 66.36X$	grain nitrogen Brady soil 1957
$Y = -56.34 + 86.39X$	grain nitrogen Brookston soil 1957
$Y = -\ 6.92 + 25.25X$	leaf nitrogen Brady soil 1957
$Y = -\ 7.30 + 37.77X$	leaf nitrogen Brookston soil 1957
$Y = -20.19 + 34.37X$	leaf nitrogen Brady soil 1958
$Y = -11.29 + 33.23X$	leaf nitrogen Brookston soil 1958

The Relation between Applied Nitrogen and the Nitrogen Content of the Ear Shoot Leaf

Because luxury consumption of nitrogen did not occur where this element was the only nutrient variable influencing yield a "critical percentage" for nitrogen does not seem to exist under conditions of these experiments. Maximum yield is directly associated with maximum leaf nitrogen percentage. In the present study, although it appeared that maximum nitrogen percentage was not reached, the point of diminishing returns from applied nitrogen had been passed. In an attempt to obtain some information on what the theoretical maximum might be, the relation between rate of nitrogen application and percentage of nitrogen in the tissue was studied.

When the amount of nitrogen applied was plotted against the logarithm of the percentage of nitrogen in the tissue, it was found that the relation was exponential and obeyed rather closely the following equations:

$N = \log_{6.009} X$ — Brookston 1957
$N = \log_{3.940} X$ — Brady 1957
$N = \log_{6.131} X$ — Brookston 1958
$N = \log_{4.49} X$ — Brady 1958

where N = percentage of nitrogen in the tissue and X = rate of nitrogen applied.

Since the relation between applied nitrogen and nitrogen content is exponential, the percentage of nitrogen in the tissue should continue to increase as the rate of nitrogen applied is increased. Admittedly the increase in nitrogen percentage becomes small as the rates of application become greater. Thus to calculate a critical percentage it is necessary to adopt an arbitrary procedure as for example the point at which yield increases are no longer of economic value.

Application of ammonium nitrate to the Brady sandy loam was more effective in increasing the nitrogen content of the ear shoot leaf than corresponding applications to the Brookston clay. This circumstance is of especial interest because the nitrogen content of the leaves of plants grown on plots receiving no nitrogen was almost identical on the two soil types in 1958. The fine texture and poor drainage of the Brookston soil may have imposed physical conditions which reduced the efficiency of applied ammonium nitrate. However, no data were collected in this study to elucidate this possibility.

The data presented herein support the contention of several workers (1, 3, 8) that the relation between leaf nitrogen percentage and yield is linear and that there is no evidence of any departure from linearity or a flex point which could be termed the "critical percentage". The fact that the absolute yield value associated with a given nitrogen percentage was different for the two soils studied limits the usefulness of the linear relationship between yield and per cent leaf nitrogen in estimating nitrogen sufficiency for corn production in this part of Ontario.

REFERENCES

1. Andharia, R. M., F. W. Schaller, and G. Stanford. Nitrogen status of Marshall silt loam as influenced by different crop rotations. Soil Sci. Soc. Amer. Proc. 17:247-251. 1953.
2. Association of Official Agricultural Chemists. Official methods of analysis. 8th ed. Washington, D.C. 1955.
3. Bennett, William F., G. Stanford, and Lloyd Dumeril. Nitrogen, phosphorus and potassium content of corn leaf and grain as related to nitrogen fertilization and yield. Soil Sci. Soc. Amer. Proc. 17:252-258. 1953.
4. Jordan, H. V., K. D. Laird, and D. D. Ferguson. Growth rates and nutrient uptake by corn in a fertilizer-spacing experiment. Agron. J. 42:261-268. 1950.
5. Krantz, B. A., and W. V. Chandler. Lodging, leaf composition and yield of corn as influenced by heavy applications of nitrogen and potash. Agron. J. 43:547-552. 1951.
6. Richards, N. R., A. G. Caldwell, and F. F. Morwick. Soil survey of Essex County. Experimental Farms Service, Dom. Dept. Agr. Report No. 11, Ontario Soil Survey. January, 1949.
7. Tyner, E. H. The relation of corn yields to leaf nitrogen, phosphorus and potassium content. Soil Sci. Soc. Amer. Proc. 11:317-323. 1946.
8. Viets, F. G., Jr., C. L. Crawford, and C. E. Nelson. The relationships among corn yields, leaf composition and fertilizer applied. Soil Sci. Soc. Amer. Proc. 18:297-301. 1954.

ABSORPTION OF FERTILIZER PHOSPHORUS BY SUGAR BEETS AS INFLUENCED BY PLACEMENT OF PHOSPHORUS AND NITROGEN[1]

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ABSTRACT

A greenhouse study was conducted to determine the effects of placement of phosphorus and nitrogen on absorption of fertilizer phosphorus by sugar beets. Seven placements of P-32-labelled concentrated superphosphate combined with three nitrogen treatments—ON, 20 lb. N mixed with the soil, and 20 lb. N applied with the phosphorus—were used. The nitrogen source was ammonium nitrate. The phosphorus placements included three band placements, two applications mixed with 2 inches of soil at the 3-5 inch depth with and without a starter, and two applications mixed with 2 inches of soil at the 0-2 inch depth with and without a starter.

The placement of nitrogen had a greater influence on the uptake of fertilizer phosphorus than did the placement of phosphorus. Nitrogen applied with the phosphorus generally resulted in greater uptake of fertilizer phosphorus than did nitrogen mixed with the soil. The nitrogen was more effective when the phosphorus was banded than when it was mixed with a volume of soil 2 inches deep. When no nitrogen was added or when nitrogen was mixed with the soil, a shallow band placement or the applications mixed with 2 inches of soil were equally effective in supplying phosphorus to the plant, and were superior to either a deep band or a mixed application with a starter. However, when nitrogen was added with the phosphorus, the shallow and deep bands were equally effective and were superior to the mixed applications with or without a starter.

INTRODUCTION

The application of fertilizer to sugar beets grown in the southwestern part of Ontario has increased greatly during the last 20 years. The soils of this region are generally low in plant-available phosphorus and could be expected to respond well to applications of fertilizer. In spite of these facts, the average yield of sugar beets per acre has increased only from 10.2 tons per acre during the 10-year period ending in 1942 to 11.4 tons per acre during the last 10 years (1). Increases in yields of most other field crops have been much greater.

One factor which may be of importance in this problem is the placement of the fertilizer. The sugar beet has a root system which is quite different from most field crops. When a seed germinates, the tap root grows directly downward without branching. When the plants are 6 to 8 weeks old lateral roots begin to appear in two rows on opposite sides of the root. At later stages of growth these laterals occur in great numbers and form an excellent absorbing system in the surface foot of soil (6, 16). The placement of the fertilizer to obtain the most efficient absorption by such a root system has not been studied to the same extent as for other field crops.

[1]Contribution from Department of Soils, Ontario Agricultural College, Guelph, Ont. Part of thesis presented by senior author to the Graduate School, University of Toronto, in partial fulfilment of requirements for M.S.A. Degree.

[2]Former Graduate Student, now Research Assistant, Purdue University, Lafayette, Indiana; and Assistant Professor of Soils, respectively.

Olsen and Gardner (11) suggested that, in order to be absorbed early in the season, at least part of the phosphorus should be placed close to the seed. Schmehl *et al.* (14) reported that after 7 weeks of growth plants had absorbed more phosphorus from fertilizer mixed with a volume of soil 4 inches wide and 4 inches deep than from a band. Four weeks later, the reverse was true. Four and five months after planting, the amounts of phosphorus absorbed from the two placements were equal. Larson (7) found that a ploughed-down application of phosphorus was superior to a broadcast or banded application. He attributed this to the fact that a small amount of the phosphorus would be close to the seed while the major portion of it would be deeper where the water regime would be more favourable later in the season.

Another factor which may be of significance in the efficiency of fertilizer use by sugar beets is the placement of nitrogen. Numerous workers (2, 3, 5, 8, 10, 13) have reported that the addition of nitrogen to a phosphorus band greatly increased the absorption of phosphorus. This effect has been studied to a little extent with sugar beets. Grunes *et al.* (5) reported that the per cent of phosphorus in sugar beet plants that was derived from the fertilizer was increased by the addition of nitrogen with the phosphorus. Miller and Ohlrogge (8) reported a 100 per cent increase in fertilizer phosphorus absorption by corn when nitrogen was added with the phosphorus regardless of soil phosphorus level. When the nitrogen was applied in a band separated from the phosphorus, the effect was greatly reduced. Other workers (2, 3, 10, 13) have reported similar findings with these and other crops.

Although this effect of nitrogen on phosphorus absorption has been ascribed to physiological, morphological, or chemical factors, no workers have as yet been able to determine the relative importance of each factor.

The objectives of the work reported herein were to study, under greenhouse conditions, the influence on phosphorus absorption during the early growth of sugar beets of (a) phosphorus placement, (b) nitrogen placement, and (c) interactions of phosphorus and nitrogen placement.

MATERIALS AND METHODS

A bulk sample of the surface horizon of a Perth clay loam was obtained from the County of Middlesex for this study. The pH was 7.4 and the dilute-acid-soluble P_2O_5 content (12) was 135 pounds per acre. This soil, which is commonly used for sugar beet production, would normally respond to applications of both phosphorus and nitrogen. The soil was passed through a "Royer" pulverizer[1] and treated with Krilium, a soil conditioner, prior to placing in No. 10 metal cans (approximately 1 U. S. gallon), lined with plastic bags. Phosphorus was applied at the rate of 100 pounds of P_2O_5 per acre, calculated on a length-of-row basis, assuming a row width of 24 inches. The material used was P-32-labelled concentrated superphosphate with a specific activity of 0.15 mc. per gm. of P_2O_5, and analysing 50.5 per cent P_2O_5[2].

[1] Distributed by Brown Engineering Corp., Toronto, and used to prepare the soil for potting.
[2] Obtained from U.S.D.A. Plant Industry Station, Beltsville, Maryland.

The phosphorus placements used were as follows:

I. Banded 1.5 inches directly below the seed.
II. Banded 1.5 inches below and 1 inch to the side of the seed.
III. Banded 4 inches below and 1 inch to the side of the seed.
IV. One-quarter of the total application placed with the seed, and the remainder mixed with 2 inches of soil at the 3-5 inch depth.
V. The entire application mixed with 2 inches of soil at the 3-5 inch depth.
VI. One-quarter of the total application placed with the seed, the remainder mixed with the top 2 inches of soil.
VII. The entire application mixed with the top 2 inches of soil.

Placements IV and V simulate a ploughed-down application with and without a starter, while Placements VI and VII correspond to a broadcast application that was disked in, with and without a starter.

Three nitrogen treatments for each phosphorus placement were included, viz., no nitrogen (N_0); nitrogen and phosphorus applied together (N_p); and nitrogen mixed throughout the soil, corresponding to a broadcast application (N_m). The source of nitrogen was ammonium nitrate, applied at the rate of 20 pounds of N per acre on the same basis as the phosphorus. Each treatment was replicated three times, each replicate forming a randomized block.

Twelve seeds of monogerm hybrid SL 108 MS x SP 5481-0, treated with Arasan[1], were placed approximately 0.25 inches deep along the diameter of the cans on January 12, 1958.

After planting, the soil surface was covered with approximately 0.5 inches of silica sand. This treatment has been found to greatly reduce surface evaporation and thus maintain moisture conditions within the pot uniform except for differences due to root concentration. The moisture content of the soil was brought up to or near the moisture equivalent value after planting and periodically thereafter by weighing each pot and adding the water that had been lost. An attempt was made to keep the moisture content above 50 per cent of available moisture, although at later stages of growth this was not always possible. The beets were thinned to six plants per can at the first true-leaf stage and to three plants per can on February 15. The remaining plants were harvested on March 15 and the oven-dry weight was determined.

The amount of fertilizer phosphorus (mgm.P) absorbed by the beets was determined on February 15, March 1, and March 15, using the in-situ technique described previously by the authors (9).

An analysis of variance was performed on the oven-dry weight of tops at the last determination date. The fertilizer phosphorus absorption data were analysed as a split-plot design; the treatments being the main plots, and the determination dates the sub-plots (4). The components for phosphorus placement and nitrogen and their interactions were broken down into single-degree-of-freedom comparisons. In addition, a sequential method of testing means was employed to determine the significance of the differences between any two means within a determination date (15).

[1] To prevent fungus infection causing damping-off.

RESULTS AND DISCUSSION

In-situ activity determinations on the seedlings 3 days after emergence showed phosphorus uptake from the band directly below the seed, from the placements that included fertilizer with the seed, and from the placement in the top 2 inches of soil. No uptake was evident from either of the bands placed 1 inch to the side of the seed or from the placement at the 3–5 inch depth. Two days later, that is ten days after planting, uptake was evident from all placements except the band 4 inches deep and 1 inch to the side. Twenty days after planting, the uptake from this placement was still lower than that of other placements. These results reflect the significance of the root distribution. Since the primary root grows directly downward without branching, a placement directly below the seed will give earlier uptake than a placement to the side at the same depth.

The oven-dry weight of tops at the final determination date is shown in Table 1. The analysis of variance revealed that the application of nitrogen caused a highly significant increase in oven-dry weight of plants. The placement of nitrogen, that is, whether the nitrogen was applied with the phosphorus or mixed with the soil, had no effect on the dry weight. The placement of phosphorus also had no effect on plant growth. Thus a direct comparison of the phosphorus uptake with and without nitrogen is not valid since it would indicate primarily the effect of the increased growth on the phosphorus uptake. However, a comparison of the phosphorus absorption from the various placements of phosphorus and from the banded or broadcast nitrogen will be independent of plant growth. For this reason, the discussion will be limited primarily to the latter comparisons.

TABLE 1.—THE OVEN-DRY WEIGHT OF SUGAR BEET TOPS 9 WEEKS AFTER PLANTING
(Gm. per plant-average of three replications)

Nitrogen treatment	Phosphorus placement No. *						
	1	11	111	IV	V	VI	VII
None	1.07	1.15	1.01	1.00	0.97	1.02	1.06
Applied with phosphorus	2.44	2.38	2.25	2.56	2.38	2.23	2.57
Mixed with soil	2.63	2.35	2.14	2.46	2.33	2.58	2.37

*As described under "Materials and Methods"

TABLE 2.—DIFFERENCES REQUIRED FOR SIGNIFICANCE AT .05 PROBABILITY LEVEL (D-VALUES) FOR COMPARISONS SHOWN IN FIGURE 1

Comparison	D-Value (mgm./plant)
N_p — 1.5 in. below vs. N_m — 1.5 in. below, 1 in. to side	1.60
N_p — 1.5 in. below vs. N_m — 1.5 in. below	1.45
N_p — 1.5 in. below, 1 in. to side vs. N_m — 1.5 in. below, 1 in. to side	1.45
N_p — 1.5 in. below vs. N_p — 1.5 in. below, 1 in. to side	1.21
N_p — 1.5 in. below, 1 in. to side vs. N_m — 1.5 in. below	1.21
N_m — 1.5 in. below N_m 1.5 in. below, 1 in. to side	1.21

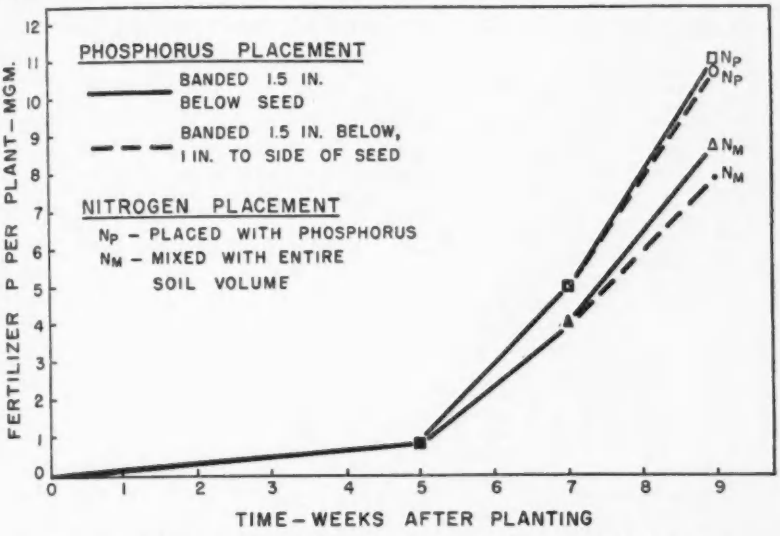

FIGURE 1. The absorption of fertilizer phosphorus by sugar beets from bands directly below and 1 inch to the side of the seed as influenced by nitrogen placement and time.

The split-plot analysis indicated that, in general, the absorption of fertilizer phosphorus was affected more by the placement of nitrogen relative to the phosphorus fertilizer than by placement of phosphorus. The mean square for phosphorus placement was 3.70, whereas that for placement of nitrogen, i.e. whether broadcast or applied with the phosphorus, was 24.85. The influence of placement of both phosphorus and nitrogen increased with time, being greatest at the last determination. Significant interactions between placement of nitrogen and placement of phosphorus precluded a detailed comparison of one factor without considering the other. Several comparisons of interest are shown in Figures 1 to 6. At any one date, the differences required for significance at the .05 probability level as shown by the sequential analysis was found to be 1.60 mgm. for those points in each figure which are separated by two other points, 1.45 mgm. for those separated by one other point, and 1.21 mgm. for adjacent points. An example of the use of these values as applied to Figure 1 is given in Table 2. The same values apply to the comparisons in succeeding figures.

Figure 1 indicates that there was no difference in phosphorus absorption from a band applied directly below the seed and a band 1 inch to the side at the same depth. Placing the nitrogen with the phosphorus resulted in greater phosphorus uptake than did mixing it with the soil.

A comparison of the shallow and deep bands placed 1 inch to the side of the seed is shown in Figure 2. The shallow band was a more effective source of phosphorus when the nitrogen was mixed throughout the soil. However, there was no difference in absorption when the nitrogen was applied in the band with the phosphorus.

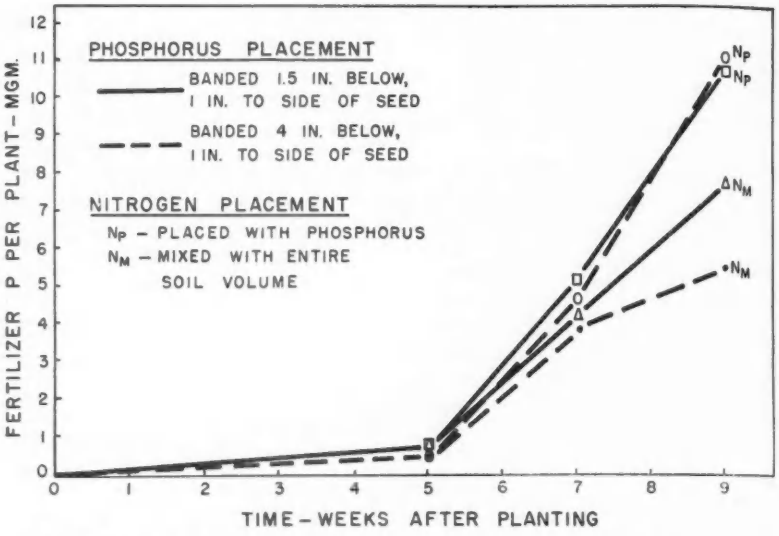
PHOSPHORUS PLACEMENT
BANDED 1.5 IN. BELOW, 1 IN. TO SIDE OF SEED
BANDED 4 IN. BELOW, 1 IN. TO SIDE OF SEED
NITROGEN PLACEMENT
NP – PLACED WITH PHOSPHORUS
NM – MIXED WITH ENTIRE SOIL VOLUME
FERTILIZER P PER PLANT – MGM.
TIME – WEEKS AFTER PLANTING

FIGURE 2. The absorption of fertilizer phosphorus by sugar beets from bands placed 1.5 inches and 4 inches below the seed as influenced by placement of nitrogen and time.

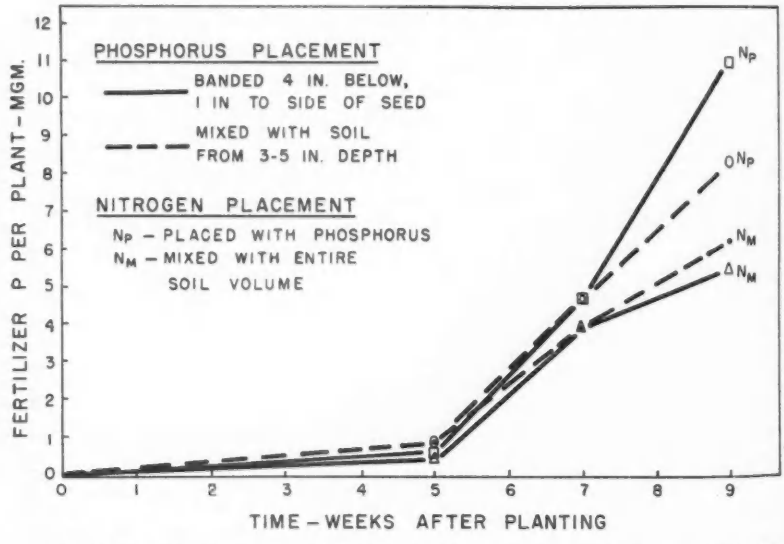
PHOSPHORUS PLACEMENT
BANDED 4 IN. BELOW, 1 IN TO SIDE OF SEED
MIXED WITH SOIL FROM 3-5 IN. DEPTH
NITROGEN PLACEMENT
NP – PLACED WITH PHOSPHORUS
NM – MIXED WITH ENTIRE SOIL VOLUME
FERTILIZER P PER PLANT – MGM.
TIME – WEEKS AFTER PLANTING

FIGURE 3. The absorption of fertilizer phosphorus by sugar beets from a band and an application mixed with a volume of soil as influenced by nitrogen placement and time.

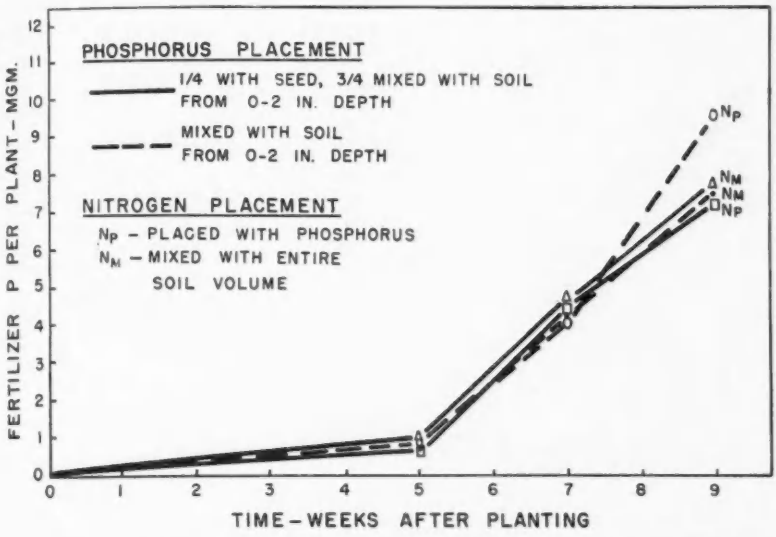
PHOSPHORUS PLACEMENT
1/4 WITH SEED, 3/4 MIXED WITH SOIL FROM 0-2 IN. DEPTH
MIXED WITH SOIL FROM 0-2 IN. DEPTH
NITROGEN PLACEMENT
NP - PLACED WITH PHOSPHORUS
NM - MIXED WITH ENTIRE SOIL VOLUME
FERTILIZER P PER PLANT - MGM.
TIME - WEEKS AFTER PLANTING
NP
NM
NM
NP

FIGURE 4. The absorption of fertilizer phosphorus by sugar beets from applications mixed with a volume of soil with and without a seed application as influenced by nitrogen placement and time.

The comparison of the effect of a deep band 1 inch to the side of the seed with that of a mixed application at the 3-5 inch depth showed that phosphorus uptake was the same from both placements when the nitrogen was broadcast (Figure 3). However, when nitrogen was placed with the phosphorus, the phosphorus absorption from a deep band was 32 per cent greater than from an application with 2 inches of soil at the same depth. This indicates that the effect of nitrogen on phosphorus uptake was greater when the nitrogen and phosphorus were banded than when they were mixed with a volume of soil.

Figure 4 shows that the method of nitrogen application did not result in significant differences in phosphorus uptake when one-quarter of the phosphorus was applied with the seed and the rest mixed with the top 2 inches of soil. However, when all the phosphorus was mixed with the soil, more phosphorus was utilized when the nitrogen was placed with the phosphorus material. These results are in contrast to those of Figure 3 which indicate that a greater response to nitrogen was obtained in a band than in a mixed application. It may be that the nitrogen when placed in direct contact with the seed caused injury which reduced the phosphorus absorption.

A comparison of four placements showed that when no nitrogen was added the shallow band or the application mixed with 2 inches of soil were equally effective in supplying phosphorus to the plants. These placements were superior to either a deep band or a mixed application with a starter as shown in Figure 5. The same results were obtained when nitrogen

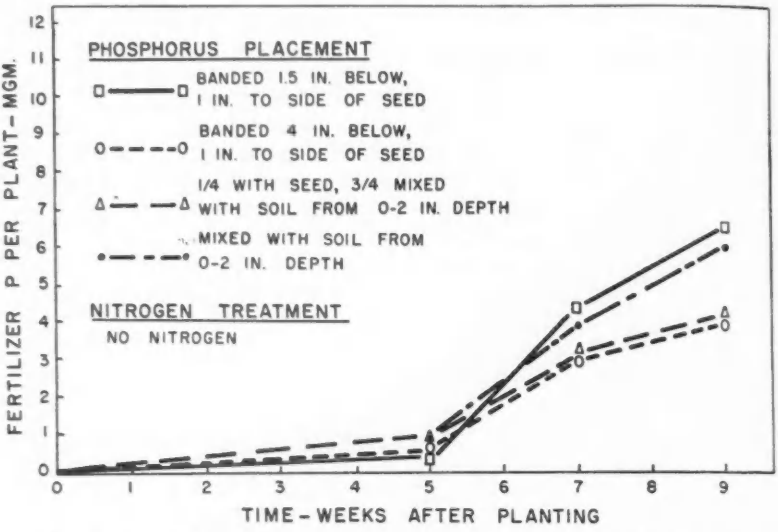
PHOSPHORUS PLACEMENT
BANDED 1.5 IN. BELOW, 1 IN. TO SIDE OF SEED
BANDED 4 IN. BELOW, 1 IN. TO SIDE OF SEED
1/4 WITH SEED, 3/4 MIXED WITH SOIL FROM 0-2 IN. DEPTH
MIXED WITH SOIL FROM 0-2 IN. DEPTH
NITROGEN TREATMENT
NO NITROGEN
FERTILIZER P PER PLANT - MGM.
TIME - WEEKS AFTER PLANTING
0 1 2 3 4 5 6 7 8 9 10 11 12

FIGURE 5. The absorption of fertilizer phosphorus by sugar beets from four placements when no nitrogen was added.

was mixed throughout the entire soil volume. However, as shown in Figure 6, when nitrogen was added with the phosphorus, the shallow and deep bands were equally effective and were superior to the mixed applications with or without a starter application. Thus, banding the nitrogen with the phosporus away from the seed was superior to mixing these two elements with 2 inches of soil.

The increased absorption of phosphorus when nitrogen was added probably resulted from the increased growth. However, it was shown that the placement of nitrogen did not have any significant effect on dry weight. Therefore, when the placement of nitrogen with the phosphorus gave a significantly higher uptake of fertilizer phosphorus than the application with the soil, it must be concluded that a factor other than growth was operative.

The results presented in Figure 2 indicate that applying the nitrogen with the phosphorus rather than mixing it with the soil doubled the absorption from the deep band but increased the absorption from the shallow band by only 37 per cent. Therefore, the influence of nitrogen on increasing phosphorus uptake was greater when the phosphorus was 4 inches deep than when it was 1.5 inches deep. The comparison in Figure 3 of the effect of the deep band with that of the application mixed with 2 inches of soil at the 3-5 inch depth showed that once the roots have reached a nitrogen-phosphorus band, the uptake therefrom is much greater than from a nitrogen-phosphorus application that is mixed with the soil at a similar

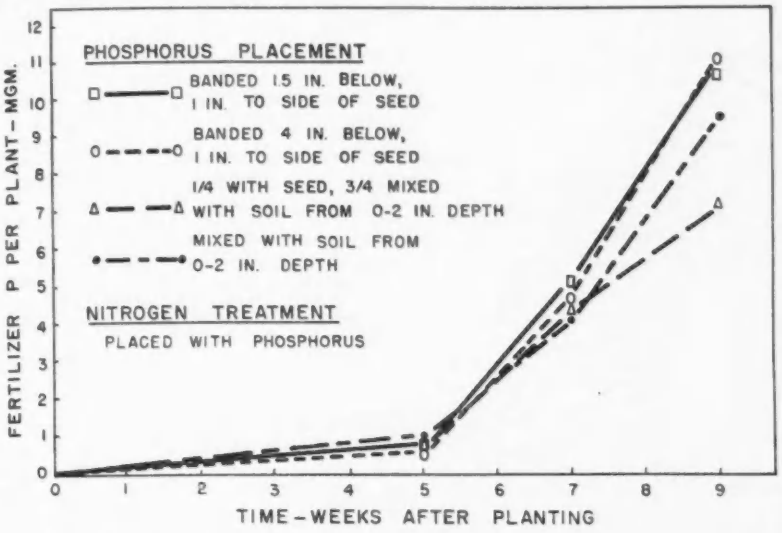

FIGURE 6. The absorption of fertilizer phosphorus by sugar beets from four placements when nitrogen was added with the phosphorus.

depth. Three factors are involved here: nitrogen and phosphorus concentration, soil volume, and depth. The nitrogen concentration is much greater in the band than it is in a volume of soil 2 inches deep. In a band, the nitrogen is in intimate contact with the phosphorus. One might, therefore, conclude that chemical effects of ammonium nitrate were responsible for the increase in phosphorus uptake. These effects, however, should be the same in the deep and shallow bands under the conditions of this experiment. Since applying the nitrogen with the phosphorus rather than mixing it with the soil caused a greater increase in fertilizer phosphorus absorption when the phosphorus was in a deep band than when it was in a shallow band, it appears that some factor in addition to possible chemical reactions was operative. This differential response with depth of placement is more likely a result of increased root growth or efficiency due to nitrogen. If this is the case, it must be concluded that the lower portions of the sugar beet root system respond to a nitrogen application more than the upper portions. Also, since the band applications gave a greater response to nitrogen than did the applications mixed with 2 inches of soil, it was concluded that a high concentration of nitrogen and/or phosphorus was essential for the initiation of the root proliferation.

ACKNOWLEDGEMENTS

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REFERENCES

1. Agricultural Statistics for Ontario. Statistics and Publications Branch, Ontario Dept. of Agriculture, Toronto.
2. Bennet, W. F., G. Stanford, and L. Dumenil. Nitrogen, phosphorus, and potassium content of the corn leaf and grain as related to nitrogen fertilization. Soil Sci. Soc. Amer. Proc. 17:252–258. 1953.
3. Chapman, H. D. Effect of nitrogenous fertilizers, sulphur, and colloidal silica on the availability of phosphorus in calcareous soils. J. Amer. Soc. Agron. 28:135–145. 1936.
4. Cochran, W. G., and G. M. Cox. Experimental designs. 2nd ed. John Wiley & Sons Inc., New York, N. Y. 1957.
5. Grunes, D. L., H. R. Haise, and L. O. Fine. Proportionate uptake of soil and fertilizer phosphorus by plants as affected by nitrogen fertilization. II. Field experiments with sugar beets and potatoes. Soil Sci. Soc. Amer. Proc. 22:49–52. 1958.
6. Hayward, H. E. The structure of economic plants. Macmillan Company, New York, N. Y. 1938.
7. Larson. W. E. Effect of method of application of double superphosphate on the yield and phosphorus uptake by sugar beets. Proc. Amer. Soc. Sugar Beet Tech. 8, Part 1:25–31. 1954.
8. Miller, M. H., and A. J. Ohlrogge. Principles of nutrient uptake from fertilizer bands. I. Effect of placement of nitrogen fertilizer on the uptake of band-placed phosphorus at different soil phosphorus levels. Agronomy J. 50:95–97. 1958.
9. Miller, M. H., and C. H. E. Werkhoven. An in-situ technique for the quantitative determination of fertilizer phosphorus in growing plants. Can. J. Soil Sci. 39: 205–214. 1959.
10. Olsen, R. A., and A. F. Dreier. Nitrogen, a key factor in fertilizer phosphorus efficiency. Soil Sci. Soc. Amer. Proc. 20:509–514. 1956.
11. Olsen, S. R., and R. Gardner. Utilization of phosphorus from various fertilizer materials: IV. Sugar beets, wheat, and barley in Colorado. Soil Sci. 68:163–169. 1949.
12. Progress Report, Department of Soils, Ontario Agricultural College, Guelph, Ont., 1957.
13. Rennie, D. A., and J. Mitchell. The effect of nitrogen additions on fertilizer phosphate availability. Can. J. Agr. Sci. 34:353–363. 1954.
14. Schmehl, W. R., S. R. Olsen, and R. Gardner. Effect of method of application on the availability of phosphate for sugar beets. Proc. Amer. Soc. Sugar Beet Tech. 8, Part 2:363–369. 1954.
15. Snedecor, G. W. Statistical methods. 5th ed. Iowa State College Press, Ames, Iowa. 1956.
16. Weaver, J. E. Root development of field crops. McGraw-Hill Book Company, Inc., New York, N. Y. 1926.

THE PERSISTENCE OF CERTAIN PESTICIDES IN THE SOIL AND THEIR EFFECT ON CROP YIELDS[1]

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ABSTRACT

From 1954 to 1958 at Kentville, Nova Scotia, the persistence and residual effects of certain pesticides, added to the soil annually from 1949 to 1953 inclusive, were investigated. Stability of pesticides in the soil rated in descending order of persistency was as follows: arsenic, DDT, BHC, chlordane. Arsenic, DDT, and sulphur caused decreases in the yields of some crops. Evidence indicated that DDT, BHC, and parathion were translocated to root crops. Increased concentrations of arsenic in the soil resulted in increased accumulations of the element in plants.

The use of lime in the soil did not ameliorate the toxic conditions resulting from the arsenic and DDT treatments, but did correct the effects of sulphur applications.

INTRODUCTION

The effects of repeated soil applications of seven pesticides, commonly used in orchard sprays, were studied from 1949 to 1953 in a field experiment at Kentville, Nova Scotia (3). The persistence of the pesticides in the soil and their effect on the growth of various crops was investigated during the subsequent 5-year period. Results obtained are given in the present paper.

MATERIALS AND METHODS

The experimental layout was a randomized block design with four replications. The individual plots were 13 feet × 16 feet and were separated by 5-foot cultivated strips. The soil in the experimental area has been classified as Berwick sandy loam (7), which is one of the common soil types in the Annapolis Valley. Details of the pesticide treatments, applied from 1949 to 1953, are given in Table 1.

Beans were grown annually from 1954 to 1958 inclusive. In addition turnips were grown in 1954, carrots in 1955, tomatoes in 1957, and peas in 1958.

Roots of the carrot crop grown in 1955, and seeds, pods, and vines of the bean and pea crops grown in 1958 were analysed for pesticide residues.

Prior to cultivation, a 6-12-6 fertilizer was applied each spring from 1954 to 1958 at 700 pounds, 900 pounds, 1500 pounds, 1000 pounds, and 1000 pounds per acre respectively. Dolomitic limestone, applied at 2.5 tons per acre in the fall of 1956, and at 1 ton per acre in the fall of 1957, was thoroughly mixed with the soil to a depth of 6 inches by rototilling.

Composite soil samples representative of the 0-6 inch depth were taken from each plot in the spring before planting and again at the end of each growing season. The following determinations were made: pesticide concentrations, soil reaction, content of exchangeable cations (calcium, magnesium, potassium), and available phosphorus.

Procedures followed in the analyses of soil and plant samples were the same as previously described (3).

[1]Contribution No. 1014, Research Station, Canada Department of Agriculture, Kentville, N.S.

RESULTS AND DISCUSSION

Persistence of Pesticides in the Soil

The soil concentrations of the pesticides are given in Table 2.

The arsenic content of the soil remained relatively constant during the 5 years of the investigation. The somewhat variable results shown for arsenic concentrations in the soil (Table 2) are attributed to soil sampling technique and to the method of analysis.

DDT, BHC, and chlordane appeared to be relatively stable in the soil, although there was a gradual decrease in concentration of these compounds in successive years. Allen *et al.* (2) reported that plots treated with 100 pounds of DDT per acre in 1947 had a residue of 28.2 pounds per acre in 1951, and that after 3 years about one-half of a 100 lb.-per-acre application of BHC had disappeared. Fleming and Maines (4) reported a loss of DDT of about 10 per cent per year over a period of 8 years. Lichenstein (8), in a study involving 14 orchards, reported a recovery of 26.6 per cent of the total amount of DDT applied as sprays during a 10-year period. Losses observed in the present 5-year study indicate an annual average loss of DDT of 12 per cent, and of BHC of 16 per cent.

Previous findings (3) indicated that parathion disappears rapidly from the soil. However, in this study it was found that minute traces of the compound or related compounds, as determined by the method followed for the determination of parathion, persisted in the soil for at least 5 years.

TABLE 1.—SOIL TREATMENTS

Pesticide	Annual application (lb./ac.)	Years of application
Lead arsenate ($PbHAsO_4$)	419	1949, 1950, 1951, 1952, 1953
DDT (50% W.P.)	209	1949, 1950, 1951, 1952, 1953
Parathion (15% W.P.)	209	1949, 1950, 1951, 1952, 1953
Sulphur (S)	1,256	1949, 1950, — — —
Ferbam (70% active ingredient)	209	1949, 1950, 1951, 1952, 1953
BHC (50% W.P., 6% gamma)	52	— 1950, 1951, 1952, 1953
Chlordane (40% W.P.)	25	— — 1951, 1952, 1953

TABLE 2.—AVERAGE VALUES FOR SPRING AND FALL CONCENTRATIONS OF PESTICIDES IN SOIL (RESULTS IN P.P.M.—AIR DRY BASIS)

Year of analysis	Arsenic(As)	DDT	Parathion	BHC	Chlordane
1954	126	136	0.43	10.8	1.80
1955	157	126	0.29	10.3	1.01
1956	149	114	0.29	7.9	1.43
1957	151	96	0.14	5.3	0.45
1958	127	76	0.09	5.1	0.34

TABLE 3.—EFFECT OF PESTICIDES ON CROP YIELDS
(AVERAGE YIELDS OF FOUR REPLICATES—POUNDS PER PLOT)

Crop	Year	Pesticides applied 1949–1953							
		Arsenic	DDT	Parathion	Sulphur	Ferbam	BHC	Chlordane	Check
Beans	1954	4.3**	2.2**	7.0	5.3*	6.8	5.9	6.5	6.8
	1955	1.8**	1.4**	5.0	2.5**	4.3	4.7	4.1	4.6
	1956	1.4**	1.5**	3.4	1.4**	3.4	3.7	3.0	3.1
	1957	3.0**	2.3**	7.7	7.7	7.9	7.9	7.7	8.0
	1958	2.5**	0.9**	5.6	5.6	5.1	5.4	5.5	4.8
Turnips	1954	36.5**	28.0	26.1	13.5	34.1**	35.5**	24.0	20.6
Carrots	1955	9.7**	8.5**	11.7	0.0**	12.5	11.4	14.1	14.1
Tomatoes	1957	96.1**	22.2**	131.4	125.4	135.1	122.5	131.7	127.1
Peas	1958	3.2**	4.3**	6.6	7.2	6.8	6.7	6.0	6.4

*Differ significantly from check at P — 0.05
**Differ significantly from check at P — 0.01

Crop Yields

The average yields are presented in Table 3.

Yields of the test crops, with the exception of turnips in 1954, were lower on the arsenic- and DDT-treated plots. The significantly higher yield of turnips on some plots was probably not due to a direct effect of the treatments. The chemicals may have reduced the turnip maggot infestation, although this was not definitely established. Foster (5) reported that most vegetable crops are sensitive to arsenic and that toxicity slowly decreased over many years. However, deeply rooted trees are apparently little affected by accumulations of arsenic at the cultivation depth. Ginsburg and Reed (6) found that high concentrations of DDT in the soil were detrimental to the growth of squash, snap beans, and some varieties of rye. Ackley *et al.* (1) reported concentrations of DDT as high as 81 p.p.m. in orchard soils and concluded that although the compound, beyond certain minimum concentrations, is toxic to plants, apple trees appear to be very tolerant to DDT in the soil.

The residual effects of the sulphur treatments were detrimental to beans in 1954, 1955, and 1956, and to carrots in 1955. The normal crop yields on the sulphur-treated plots in 1957 and 1958 reflect the lime treatments applied in the fall of 1956 and 1957. With the exception of the turnip crop, in 1954 yields on the parathion, ferbam-, BHC-, and chlordane-treated plots were not significantly different from those on the check.

Pesticide Content of Crops

Chemical analyses of plants grown in 1958 on soils treated with arsenic and on untreated soil are presented in Table 4. The results show the higher concentrations in the crops grown on the treated plots 5 years after treatments were discontinued, and also the distribution of arsenic in the plants. An examination of the carrot crop grown in 1955 to determine

TABLE 4.—ARSENIC CONTENT OF PLANTS—1958
(RESULTS IN P.P.M. AS—FRESH WEIGHT BASIS)

Crop	Plant part	Check plots	Arsenic plots
Peas	Seeds	0.01	0.18
	Pods	0.05	0.88
	Vines	0.12	2.14
Beans	Seeds	0.01	0.07
	Pods	0.27	0.79
	Leaves	0.21	1.92

the degree of translocation of the pesticides showed concentrations in the roots as follows: arsenic (As), 0.40 p.p.m.; DDT, 3.34 p.p.m.; BHC, 0.94 p.p.m.; parathion, 0.01 p.p.m. The DDT and parathion residues were located only on or in the surface scrapings of the roots; arsenic and BHC were found throughout the roots. BHC caused off-flavours in the carrots.

Effects of Pesticides on the Chemical Composition of the Soil

Results of chemical analyses of soil samples indicated that, with the exception of sulphur, applications of the various pesticides did not affect soil reaction, levels of exchangeable cations, or available phosphorus. In 1954, 1955, and 1956 soil acidity was significantly higher and exchangeable calcium and magnesium significantly lower in the sulphur-treated plots than in the checks.

There was a decrease in soil acidity and an increase in exchangeable calcium and magnesium in all plots as a result of the applications of dolomitic limestone in 1956 and 1957. However, in 1957 and 1958 differences between the sulphur-treated plots and the checks were still significant with respect to exchangeable calcium.

REFERENCES

1. Ackley, W. B., K. C. Walker, and N. R. Benson. DDT residues in orchard soils. Proc. 46th Annual Meeting, Washington State Hort. Assoc., pp. 85–88. 1950.
2. Allen, N., *et al.* Persistence of BHC, DDT and toxaphene in soil and the tolerance of certain crops to their residues. U.S.D.A. Tech. Bull. 1090. Washington, D.C. 1954.
3. Chisholm, D., A. W. MacPhee, and C. R. MacEachern. Effects of repeated applications of pesticides to soil. Can. J. Agr. Sci. 35:433–439. 1955.
4. Fleming, W. E., and W. W. Maines. Persistence of DDT in soils of the area infected by the Japanese beetle. J. Econ. Entomol. 46:445–449. 1953.
5. Foster, Arthur C. Some plant responses to certain insecticides in the soil. U.S.D.A. Circ. 862. Washington, D. C. 1951.
6. Ginsburg, M., and J. P. Reed. A survey of DDT-accumulation in soils in relation to different crops. J. Econ. Entomol. 47:467–474. 1954.
7. Harlow, L. C., and G. B. Whiteside. Soil survey of the Annapolis Valley fruit growing areas. Can. Dept. Agr. Bull. 47. Publ. 752. November, 1943.
8. Lichenstein, E. P. DDT accumulations in mid-western orchard and crop soils treated since 1945. J. Econ. Entomol. 50:545–547. 1957.
9. Overley, F. L. Cover crops in apple orchards on arsenic-toxic soils. Wash. Agr. Expt. Sta. Bull. 514. 1950.

NITRATE-SUPPLYING POWER OF EIGHT GRASSLAND SOILS OF THE KAMLOOPS, B.C., AREA AND CORRELATION WITH RANGE FORAGE PRODUCTION[1]

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ABSTRACT

The formation of nitrate in eight grassland soils of the Kamloops, British Columbia, area was studied using a laboratory incubation technique. All the accumulative totals of nitrate nitrogen produced by these soils were low and suggest that the amount of nitrate formed may be inadequate for optimum plant growth. The desert-like soils, although they are regarded as being members of the Brown great soil group, released the most nitrate nitrogen. The Shallow and Degrading Black soils released nitrate in intermediate amounts while the Brown and Dark Brown soils produced the smallest quantities. The correlations between the accumulative total of nitrate released during incubation with: C/N ratio, total nitrogen and organic matter, were not highly significant. Poor correlation was obtained in the comparison between the accumulative total nitrate formed and the forage produced during the period 1954–1957.

INTRODUCTION

The grasslands of southern British Columbia were being grazed soon after the beginning of large scale settlement in 1858 (27). Due to overstocking, depletion of these ranges set in quite soon and at present only a relatively small portion of the region possesses vegetation in climax condition (26). As a result of overgrazing, the climax vegetation, dominated by relatively tall-growing perennial bunchgrasses, has been succeeded by sagebrush and other semi-desert shrubs, as well as by less desirable grasses and forbs in the more mesic vegetative zones. Changes in vegetation due to overgrazing have occurred in many other grassland belts but not to the same extent as in the Kamloops area (26). Presumably the explanation is one of aridity and accessibility.

These grasslands are of vital importance to the range industry as sources of spring, fall and winter grazing (27). Restoration of these overstocked areas is of extreme importance. Recently, it has been shown that nitrogen fertilization could be a useful practice for correction of poor range condition (14). Sixty pounds of N per acre were applied to native stands of bluebunch wheatgrass on a Brown soil in the South Okanagan district of British Columbia. Increases in yield were accompanied by a higher protein content and the numbers of bluebunch wheatgrass culms were increased resulting in greater ground cover for the species. Nitrogen has also been used in other regions (4, 5, 13, 14, 17, 20, 22) to improve range conditions and consequent carrying capacities.

The nitrogen status of grassland soils in the Kamloops area should be evaluated as evidence indicates that nitrogen often limits the production of range forage and that it may improve range condition. The rate of change

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TABLE 1.—SOME PROPERTIES OF SURFACE SOIL (0–6 INCHES) OF THE EIGHT GRASSLAND SOILS[1]

Sample number	Soil group and sample location	Vegetative zone	Colour[2]	Texture	pH[3]	Organic matter[3] (per cent)	Total nitrogen[3] (per cent)	C:N Ratio
1	Brown (North Kamloops dump)	Lower grassland	Dark greyish brown 10 YR 4/2	Loam	7.06 ± 0.07[4]	3.44 ± 0.22	0.147 ± 0.017	13.5
2	Brown (Sheep range)	Lower grassland	Brown 10 YR 4/3	Sandy loam	7.10 ± 0.09	2.41 ± 0.19	0.178 ± 0.012	7.9
3	Dark Brown (Hayward lease)	Middle grassland	Dark brown 10 YR 3/3	Sandy loam	6.90 ± 0.10	3.47 ± 0.32	0.218 ± 0.016	9.2
4	Shallow Black (Lac du bois)	Upper grassland	Very dark brown 10 YR 2/2	Sandy loam	6.97 ± 0.11	9.05 ± 0.60	0.425 ± 0.056	12.3
5	Shallow Black (Soda lake)	Upper grassland	Very dark brown 10 YR 2/2	Sandy loam	6.56 ± 0.10	9.60 ± 0.54	0.251 ± 0.047	22.2
6	Degrading Black (Our lake)	Douglas fir	Very dark greyish brown 10 YR 3/2	Sandy loam	6.61 ± 0.10	11.69 ± 0.53	0.398 ± 0.005	17.1
7	Dark Brown (Schiedam flats)	Middle grassland	Dark brown 10 YR 3/3	Sandy loam	6.83 ± 0.04	3.31 ± 0.21	0.187 ± 0.019	10.3
8	Brown (Harper range)	Douglas fir—pine savannah	Dark greyish brown 10 YR 4/2	Loamy sand	6.72 ± 0.04	3.84 ± 0.14	0.211 ± 0.025	10.6

[1]Detailed chemical analyses for similar soils of the same region are given by Spilsbury and Tisdale (23).
[2]Munsell colour notations for dry soil.
[3]Means of 5 samples.
[4]Standard errors are also given.

of organic nitrogen to nitrate nitrogen (nitrate-supplying power) is the soil property that has been shown (6, 10) to be most closely correlated with soil capacity to supply nitrogen to crops. Laboratory incubation methods (6, 7, 10, 12, 21, 24) have provided a good measure of the ability of a soil to supply available nitrogen to plants. These tests correlated well with crop response to nitrogen fertilization in field and greenhouse trials (3, 6, 9, 12, 16).

The objectives of this investigation were twofold: (1) to measure the nitrate-supplying power of eight grassland soils of the Kamloops area and to correlate this property with several other soil characteristics; and (2) to determine the degree of correlation between nitrate-supplying power and the production of range forage.

MATERIALS AND METHODS

Five surface samples (0-6 inches) from each of eight grassland soils of the Kamloops, British Columbia, area were obtained the last day of October 1958 and were subsequently air-dried, sieved and stored for analysis[1]. The period of storage approached 18 weeks as suggested by Harpstead and Brage (11). Some characteristics of these soils are listed in Table 1. Soil colours were determined using a Munsell colour chart (15). The Bouyoucos hydrometer method (1) was used to obtain the percentages of sand, silt and clay which were used to obtain the textural class from a textural triangle. Determinations of pH were made on a 1:1 soil-water suspension according to the recommendations made by Peech *et al.* (19). The organic matter contents were evaluated by the method described by Peech *et al.* (18). Total nitrogen was determined using the micro Kjeldahl method employed by the University of Saskatchewan[2]. The laboratory incubation method of Kresge and Merkle (12) was used for measuring the rate of nitrate formation.

The sampling technique used to obtain the yields of forage, listed in Table 2, first required the selection of a suitable site. Within this area a metal pin was thrown at random with the centre of the plot area being determined by the resting place of the pin. On opposite sides, ten paces from this point, two plot centres were located. Additional plots were placed along two parallel lines, the centres of which were the two points selected above, and which were perpendicular to an imaginary line joining these same centres. On these lines two plots were located at ten-pace intervals on both sides of the centre plots. At all plot centres a metal plot cutter was used to inscribe a circular plot with an area of 9.6 square feet. The old growth was then removed and the plots were hand-harvested using sheep shears. All the forage was bagged and subsequently oven-dried and weighed. The total weight, in grams, of the ten plots at each site is equivalent to the pounds of forage produced per acre.

[1]The authors are grateful to H. J. Hortie, Pedologist, Soil Survey Unit, Research Station, University of British Columbia, Vancouver, B.C., for his guidance in the soil sampling.
[2]Mimeographed outline. Dept. of Soil Science, University of Saskatchewan, Saskatoon, Sask.

TABLE 2.—TOTAL YIELDS OF FORAGE OBTAINED FROM THE EIGHT GRASSLAND SOILS DURING THE PERIOD 1954–57

Sample number	Soil group and sample location	Pounds of dry matter per acre[1]					Range condition[4]
		1954	1955	1956	1957	Average	
1	Brown (North Kamloops dump)	484 ± 46[2]	321 ± 20	625 ± 43	426 ± 52	464 ± 64	Excellent
2	Brown[3] (Sheep range)	75 ± 10	83 ± 12		65 ± 9	74 ± 5	Poor
3	Dark Brown (Hayward lease)	577 ± 24	758 ± 80		460 ± 35	598 ± 87	Good
4	Shallow Black (Lac du bois)	1532 ± 39	1900 ± 120	1240 ± 114	912 ± 62	1396 ± 211	Good
5	Shallow Black (Soda lake)	510 ± 35	285 ± 25		430 ± 40	408 ± 65	Poor
6	Degrading Black (Our lake)	814 ± 60	760 ± 80	752 ± 101	639 ± 10	741 ± 37	Excellent
7	Dark Brown[3] (Schiedam flats)	160 ± 25	185 ± 30		135 ± 16	160 ± 56	Poor
8	Brown (Harper range)	338 ± 42	167 ± 21	162 ± 28	69 ± 10	184 ± 15	Poor

[1]Under proper management only 50-60 per cent of total forage available should be used.
[2]Standard errors are also given.
[3]Heavily grazed in the past; thus present yields are a poor measure of both potential and actual production.
[4]Based on density, composition and vigour of plant cover, amount of litter and soil stability.

TABLE 3.—COMPARISON OF THE ACCUMULATIVE TOTAL OF NITRATE NITROGEN RELEASED DURING INCUBATION WITH CARBON TO NITROGEN RATIO, TOTAL NITROGEN, ORGANIC MATTER AND FORAGE PRODUCTION[1]

	C:N ratio	Total nitrogen	Organic matter	Forage production			
				1954	1955	1957	Average
Correlation coefficient (r)	0.55	0.48	0.45	0.29	−0.01	0.30	0.18
	(0.20)	(0.20)	(0.30)	(0.45)	(−)	(0.45)	(0.65)

[1]Correlation coefficients are significant only at the probability levels given in brackets below.

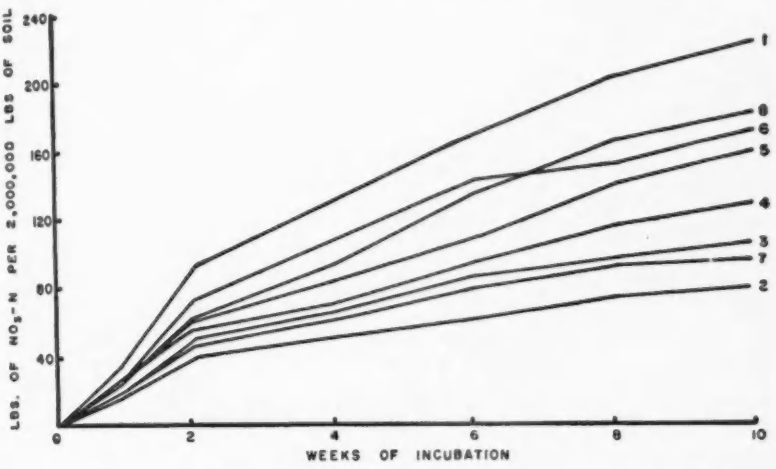

FIGURE 1. Accumulative totals of nitrate nitrogen produced by the eight grassland soils during a 10-week incubation period.

RESULTS AND DISCUSSION

Figure 1 shows the nitrate nitrogen produced by the eight grassland soils over a 10-week incubation period. Soils 1 and 8, which are desert-like in appearance, released the most nitrate. The Shallow and Degrading Black soils (4, 5 and 6) formed nitrate in intermediate amounts, while the Brown and Dark Brown soils (2, 3 and 7) produced the smallest quantities. These data suggest that the amount of nitrate formed may be inadequate for optimum plant growth. For example, a 1-ton crop of ryegrass will remove approximately 100 pounds of nitrate nitrogen per acre while a 2-ton crop of timothy will absorb some 220 pounds of nitrate per acre. The rate of nitrate formation is also an important consideration since growth occurs mainly during the short period of April to June (26). Forage yields may be reduced if nitrate release is not rapid enough to meet growth requirements.

In Table 1, it can be seen that soils 4, 5 and 6 contained the most organic matter, had the highest total nitrogen content and had high C/N ratios. Of these soils, 4 and 5 belonged to the upper grassland area of the southern interior of British Columbia. In this area there is usually a heavy sod, the result of a much denser cover of grasses and forbs than is encountered in either the lower or middle grassland zones (23). The other soil belonged to the Douglas fir zone, also described by Spilsbury and Tisdale, where there is a well-developed ground cover dominated by perennial grasses and forbs. The intermediate rate of nitrate formation by these soils may be due to the perennial grass sods retaining most of the mineralized nitrogen in organically bound forms (10).

Soils 3 and 7 occurred in the middle grassland zone and soil No. 2 was in the lower grassland zone. These zones have extremely warm temperatures, low precipitation and high evaporation (26). The small C/N ratios appearing in Table 1 indicate that such climatic conditions may have led to more complete decomposition of soil organic substances. The low nitrate nitrogen release by soils 3, 7 and 2 may have been due to increased resistance of these substances to mineralization as the degree of decomposition advances (25).

Soil No. 1, although located in the lower grassland zone, produced the most nitrate nitrogen. The range supported by this soil was in excellent condition (cf. Table 2) perhaps from being ungrazed for years due to lack of watering facilities in the immediate area. Point sampling (2) indicated that bluebunch wheatgrass was the principal species growing on this soil. This grass through its extensive root system (28) may have provided sufficient organic substances to result in high nitrate release. Soil No. 8, which closely resembled soil No. 1, appeared in a Douglas fir-pine savannah zone where range condition was poor. There was a complete absence of wheatgrass on this soil and the grass cover was less than that of soil 1. The absence of this grass and the probable reduction of active organic matter may explain the lower production of nitrate observed when soils No. 1 and 8 are compared. Tisdale (26) regarded bluebunch wheatgrass as the species which bound the lower, middle and upper grassland zones into one unit. Textural differences could have influenced the formation of nitrate nitrogen. Soil No. 1, which was the heavier textured, may have provided more favourable moisture conditions for nitrate release* (8).

In Table 3 the accumulative totals of nitrate nitrogen released during incubation are compared with the carbon to nitrogen ratios; the total nitrogen, the organic matter, and with forage production. The correlation coefficients (r) obtained for the C/N ratio, total nitrogen and organic matter were not highly significant. These coefficients should not be disregarded since this degree of significance was obtained with only eight soils. If more soils had been studied the consequent increase in the number of degrees of freedom might have led to greater sensitivity. From the studies summarized by Harmsen and Van Schreven (10), considerable correlation was expected between the amount of nitrate released and total soil nitrogen, as well as with C/N ratios.

The poor correlation between the accumulative total of nitrogen released and the forage produced is not surprising in view of the wide range in climatic conditions occurring in the area. Here a gradual succession of changes in both soils and vegetation occurred with differences in elevation which has been referred to as "vertical zonation" (23, 26). The Brown soils occurred in an arid climate, while the Shallow and Degrading Black soils were present in a zone characterized by higher precipitation and lower temperatures. At the higher elevations soil moisture was believed to be more effective in promoting plant growth because of lower evaporation. Since both nitrogen and water are known to make important contributions to vegetative bulk, it may be readily appreciated that more favourable soil moisture conditions could result in greater forage production. In addition,

*Utah Agr. Expt. Sta. Progress Rept., for Regional Project W-31. Mimeo. 1956.

higher soil moisture may have resulted in greater forage yields through improved nitrate levels. The yields (Table 2) were indeed much greater for the Shallow and Degrading Black soils with ranges in good condition than they were for the Brown and Dark Brown soils supporting range vegetation in a similar condition. Since the soils producing the greatest yield of forage formed only intermediate amounts of nitrate nitrogen, some other factor such as moisture must have been responsible for the discrepancy. The importance of moisture was again suggested when the yields for soil No. 1 were reviewed. Here the yields were comparable with those obtained from soils No. 3 and 5. The heavier texture and the resulting increase in moisture-holding capacity has apparently tended to offset the decrease in precipitation and increases in temperature and evaporation. Other factors such as soil fertility, soil depth, slope and exposure might obscure the relationship between accumulative totals of nitrate released and yields of forage.

REFERENCES

1. Bouyoucos, J. G. A recalibration of the hydrometer method for making mechanical analysis of soil. J. Amer. Soc. Agron. 43:434–437. 1951.
2. Brown, Dorothy. Methods of surveying and measuring vegetation. Bull. 42. Commonwealth Bureau of Pastures and Field Crops. Crown Press, Reading, England. 1954.
3. Cook, F. D., F. G. Warder, and J. L. Doughty. Relationship of nitrate accumulation to yield response of wheat in some Saskatchewan soils. Can. J. Soil Sci. 37:84–88. 1957.
4. Cooper, Glee S., and W. A. Sawyer. Fertilization of mountain meadows in Eastern Oregon. J. Range Management 8:20–22. 1955.
5. Dickey, P. B., O. K. Hoglund, and B. A. Madson. Effect of fertilizers on the production and season of use of annual grass range in California. J. Amer. Soc. Agron. 40:186–188. 1948.
6. Eagle, D. J., and B. C. Matthews. Measurement of nitrate-supplying power of soils by an incubation method and correlation with crop yield response. Can. J. Soil Sci. 38:161–170. 1958.
7. Fitts, J. W., W. V. Bartholomew, and H. Heidel. Correlation between nitrifiable nitrogen and yield response of corn to nitrogen fertilization on Iowa soils. Soil Sci. Soc. Amer. Proc. 17:119–122. 1953.
8. Greaves, J. E., and E. G. Carter. Influence of moisture on bacterial activities of the soil. Soil Sci. 10:361–367. 1920.
9. Hanway, J., and L. Dumenil. Predicting nitrogen fertilizer needs of Iowa soils: III. Use of nitrate production together with other information as a basis for making nitrogen fertilizer recommendations for corn in Iowa. Soil Sci. Soc. Amer. Proc. 19:77–80. 1955.
10. Harmsen, G. W., and D. A. Van Schreven. Mineralization of organic nitrogen in soil. *In* Advances in Agronomy. Vol. 7. A. G. Norman, ed. Academic Press, Inc., New York, N.Y. 1955.
11. Harpstead, M. I., and B. L. Brage. Storage of soil samples and its effect upon the subsequent accumulation of nitrate nitrogen during controlled incubation. Soil Sci. Soc. Amer. Proc. 22:326–328. 1958.
12. Kresge, C. B., and F. G. Merkle. A study of the validity of laboratory techniques in appraising the available nitrogen producing capacity of soils. Soil Sci. Soc. Amer. Proc. 21:516–521. 1957.
13. Mader, E. L. The influence of certain fertilizer treatments on the native vegetation of Kansas prairie. Diss. Abstr. 17:209–210. 1957.
14. Mason, J. L., and J. E. Miltmore. Increase in yield and protein content of native bluebunch wheatgrass from nitrogen fertilization. Can. J. Plant Sci. 39:501–504. 1959.
15. Munsell Color Company, Inc., Baltimore, Maryland.
16. Munson, R. D., and G. Stanford. Predicting nitrogen fertilizer needs of Iowa soils: IV. Evaluation of nitrate production as a criterion of nitrogen availability. Soil Sci. Amer. Proc. 19:464–468. 1955.

17. Nelson, M., and E. N. Castle. Profitable use of fertilizers on native meadows. J. Range Management 11:80–83. 1958.
18. Peech, M., L. T. Alexander, L. A. Dean, and J. F. Reed. Methods of soil analysis for soil fertility investigations. U.S.D.A. Circ. 757. Washington, D.C. 1947.
19. Peech, M., R. A. Olsen, and G. H. Bolt. The significance of potentiometric measurements involving liquid junction in clay and soil suspensions. Soil Sci. Soc. Amer. Proc. 17:214–218. 1953.
20. Rogler, G. A., and R. J. Lorenz. Nitrogen fertilization of Northern Great Plains rangelands. J. Range Management 10:150–160. 1957.
21. Saunder, D. H., B. L. Ellis, and A. Hall. Estimation of available nitrogen for advisory purposes in Southern Rhodesia. J. Soil Sci. 8:301–312. 1957.
22. Smith, D. R., and R. L. Lang. The effect of nitrogenous fertilizers on cattle distribution on mountain range. J. Range Management 11:248–249. 1958.
23. Spilsbury, R. H , and E. W. Tisdale. Soil-plant relationships and vertical zonation in the southern interior of British Columbia. Sci. Agr. 24:395–436. 1944.
24. Stanford, G., and J. Hanway. Predicting nitrogen fertilizer needs of Iowa soils: II. A simplified technique for determining relative nitrate production in soils. Soil Sci. Amer. Proc. 19:74–77. 1955.
25. Thompson, L. M., and C. A. Black. The mineralization of organic phosphorous nitrogen and carbon in Clarion and Webster soils. Soil Sci. Soc. Amer. Proc. 14:147–151. 1950.
26. Tisdale, E. W. The grasslands of the southern interior of British Columbia. Ecology 28:346–382. 1947.
27. Tisdale, E. W., A. McLean, and S. E. Clarke. Range resources and their management in British Columbia. J. Range Management. 7:3–9. 1954.
28. Weaver, J. E. A study of the root systems of prairie plants of southeastern Washington. Plant World 18:227–248; 273–292. 1915.

PHOSPHORUS FRACTIONS IN A SOIL SAMPLED AT DIFFERENT DEPTHS AND THE EFFECT OF LIME AND FERTILIZER ON OATS AND CLOVER IN A GREENHOUSE TEST[1]

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ABSTRACT

Soil samples were collected at four different depths from a virgin soil, and in a region where deep ploughing has been a common practice. Chemical analyses revealed that the sub-surface samples were more highly saturated with bases than were the surface samples. In the 0-6 inch layer the percentage contribution of calcium, aluminium and iron phosphate to total soil phosphorus was 41.1, 10.4 and 2.8 respectively; while, in the 18-24 inch layer the percentages were 88.4, 2.8 and 0.5 respectively. Organic phosphorus decreased with depth.

In the greenhouse there were highly significant differences between oat yields on the various layers, the surface soil giving the highest yields. Clover crop yields tended to be better as depth of profile increased. Phosphorus increased oat yields and clover yields on all soil layers. As a result of overliming in certain instances clover yields were depressed in the absence of applied phosphate fertilizer, whereas oat yields were unaffected.

INTRODUCTION

In many parts of northwestern Quebec within the great Clay Belt, relatively deep ploughing—down to 24 inches—has been used for breaking new land. The two main reasons for such a procedure are, first, that it aids in the removal of brush and twigs and, second, that a more suitable soil condition is promoted for plant growth. Farmers have attested to increased hay yields on these deep ploughed areas. In this investigation the objective was: to observe crop yields under greenhouse conditions, study the soil phosphorus fractions, and evaluate the effects of lime and fertilizer on a virgin soil sampled at different depths. This information is useful when studied in conjunction with physical soil analyses and field plot experiments involving various depths of ploughing.

LITERATURE REVIEW

The importance of sub-soil nutrients did not until recently receive the fullest attention of soils research workers. Difficulties of techniques were a controlling factor. The effect of sub-soil nutrients is difficult to assess in the field; consequently, most of the available information has been by way of pot experiments.

Rost (9) found that for humid regions the lower A and upper B soil horizons were more deficient in phosphorus than was the surface soil. Stanford and Pierre (11), in reviewing Stelly's work, however, observed that availability of phosphorus in certain Iowa soils was greater in the lower B and C horizons than in the surface layer. Recently, Halstead *et al.* (6) studied phosphorus and potassium supply for alfalfa in six soils sampled at different depths. The results of these workers indicated that,

[1]Contribution from Research Branch, Canada Department of Agriculture, Experimental Farm, Kapuskasing, Ont.

for most of the soils studied, the phosphorus-supplying power of the surface soil was considerably greater than that of the corresponding sub-surface samples; acid-soluble phosphorus extracted from five of the soils increased with depth and the $NaHCO_3$ soluble phosphorus in surface samples from a similar number of soils was higher than that in the sub-surface samples. Englebert and Truog (5) in experiments carried out in the field have observed that differential crop response on deep ploughed soil could be explained on the basis of different root structures with their ensuing effect on nutrient availability. Chang and Jackson (3) have shown that with two silt loam profiles the greater quantity of calcium phosphates in the sub-soil as compared to the surface soil was correlated with the 0.002N H_2SO_4—extractable phosphorus.

EXPERIMENTAL MATERIALS AND METHODS

The Grey Wooded soil under study occurs at Guyenne, northwestern Quebec, in the Canadian Shield area, and has developed under forest cover. At present no detailed soil survey has been made of the area; hence, soil names are not available.

From a field experimental area of virgin soil, samples at 0-6 inch, 6-12 inch, 12-18 inch and 18-24 inch depths were collected, air-dried, crushed and passed through a half-inch mesh sieve. The depths of sampling were chosen for practical reasons, and also in view of the fact that there was not much differentiation with respect to layers in the profile. After thorough mixing, the soils were placed on a weight basis in glazed gallon plots. Samples of the air-dried soil from the different layers were passed through a 2-mm. sieve and retained for chemical analyses.

A split-plot factorial design was used, with the four soil layers as main plots and applied treatments as sub-plots in three replications. The sub-plot treatments consisted of a 2 × 2 factorial and one additional treatment. There were two rates of hydrated lime, 0 and 3.85 tons per acre; two rates of phosphorus, 0 and 200 pounds per acre. All pots received 120 pounds K_2O per acre. The additional treatment consisted of the highest rate of hydrated lime and phosphorus, and 120 pounds of K_2O. Nitrogen at the rate of 40 pounds per acre was added to all pots excepting those containing the additional treatment. Ajax Oats and inoculated Altaswede clover in separate pots were the indicator crops used. The hydrated lime treatments were mixed into the soil 1 month prior to seeding.

With respect to chemical analyses of the various soil layers, exchange capacity, exchangeable bases and organic matter determinations were carried out as outlined by Peech *et al.* (7). Nitrogen was determined by the Kjeldahl method and lime requirements as outlined by Dunn (4). Soil pH was determined by means of a glass electrode using 1:1 soil:water ratio. Acid soluble plus adsorbed, and adsorbed phosphorus were extracted by the Bray methods (1) and phosphorus determined by a modified Truog and Meyer method (12). The modification consisted of adding sodium bisulphite and boric acid to repress the effect of iron and fluoride ions respectively. Total phosphorus was determined by the modified Truog and Meyer procedure (12) after acid digestion by the Sherman method (10). Fractionation of soil phosphates involved the use of the Chang and Jackson procedure (2).

At harvest, composite samples of the above-ground parts of oats (grain + straw) and of clover were ground in the Wiley Mill for determining total phosphorus uptake. Organic matter in the plant materials was destroyed by nitric, sulphuric, and perchloric acids as outlined by Piper (8). Phosphorus was determined by the method of Truog and Meyer (12). The pH of the soil from each treatment was determined at the end of the experiment.

RESULTS AND DISCUSSIONS

In Table 1 are recorded some chemical characteristics of the various soil layers. The acidity of the soil decreased with depths of the layers. The sub-surface samples were more highly saturated with bases than were the surface samples. Exchangeable calcium, magnesium, and potassium all increased with depth to the 12-18 inch layer. The limestone requirement for the 0-6 inch layer was particularly high in relation to the other layers. Percentage nitrogen decreased with depth, but organic matter decreased with depth only to the 12-18 inch layer. Bray adsorbed phosphorus was highest in the surface soil, whereas the Bray acid-soluble phosphorus increased with depth. The relatively higher values for Bray adsorbed phosphorus in the surface soil as compared to the sub-surface soil would suggest a greater adequacy of phosphorus in the surface soil; however, the increase in pH of the samples with increasing depth would be expected to be favourable for the availability of phosphorus in the sub-soils.

The distribution of inorganic phosphorus, and the organic phosphorus within each soil depth, are shown in Table 2. Total phosphorus content of the soil layers varied from 425 p.p.m. of soil in the 6-12 inch layer to

TABLE 1.—CHEMICAL PROPERTIES OF THE DIFFERENT SOIL LAYERS

Chemical characteristics	Depths			
	0–6″	6–12″	12–18″	18–24″
pH	5.10	5.50	6.15	6.60
Organic matter %	2.47	0.90	0.40	0.43
Nitrogen %	0.101	0.052	0.041	0.026
Exchange capacity m.e./100 gm.	24.89	31.80	34.03	32.18
Exchangeable calcium m.e./100 gm.	4.98	11.24	13.45	13.32
Exchangeable magnesium m.e./100 gm.	3.00	6.94	8.32	8.41
Exchangeable potassium m.e./100 gm.	0.45	0.49	0.54	0.48
Adsorbed phosphorus p.p.m. of soil	15.4	6.8	4.3	4.4
Acid-soluble phosphorus p.p.m. of soil	21.4	58.0	109.5	139.1
Limestone requirement (pH 7) tons per acre	7.4	2.8	1.8	0.8

TABLE 2.—SOIL PHOSPHORUS FRACTIONATION OF VARIOUS SOIL LAYERS

	0–6″ layer		6–12″ layer		12–18″ layer		18–24″ layer	
	p.p.m. of soil	% of total	p.p.m. of soil	% of total	p.p.m. of soil	% of total	p.p.m. of soil	% of total
Aluminium-phosphates	47.5	10.4	22.5	5.3	15.0	3.2	15.0	2.8
Calcium-phosphates	187.5	41.1	287.5	67.6	412.5	87.9	475.5	88.4
Iron-phosphates	12.9	2.8	2.8	0.7	2.5	0.5	2.7	0.5
Organic phosphates	80.0	17.5	50.0	11.8	20.5	4.4	20.0	3.7
"Residual phosphates"	128.1	28.1	62.2	14.6	18.5	3.9	24.8	4.9
Total	456		425		469		538	

TABLE 3.—AVERAGE YIELD OF OATS AND CLOVER ON DIFFERENT LAYERS OF SOIL

Treatment	Oats (Grain)				Clover (Dry Matter)			
	0–6″	6–12″	12–18″	18–24″	0–6″	6–12″	12–18″	18–24″
	gm./pot	gm./pot	gm./pot	gm./pot	gm./pot	gm./pot	gm./pot	gm./pot
1. NK	2.31	2.28	1.67	2.00	11.19	14.39	16.31	18.50
2. NPK	4.24	3.28	2.59	2.80	17.02	20.40	24.46	19.67
3. NKL (Lime)	2.58	2.41	1.86	1.87	16.58	6.90	4.55	6.68
4. NPKL	6.07	2.97	2.40	2.20	18.56	22.67	16.04	17.33
5. PKL	5.27	1.55	0.97	0.69	17.76	20.92	21.18	22.63

TABLE 4.—ANALYSIS OF VARIANCE OF DATA RELATING TO OAT AND CLOVER YIELDS

Source of variation	D.F.	Oat		Clover	
		M.S.	F value	M.S.	F value
Replications	2	0.210	1.26	0.50	—
Depths (D)	3	15.92	95.33**	2.30	—
Error (a)	6	0.167	—	2.39	—
Phosphorus (P)	1	17.112	97.12**	698.45	157.81**
Lime (L)	1	0.264	—	200.47	45.29**
P × L	1	0.011	—	66.53	15.03**
NPKL vs. PKL (1)	1	10.153	57.62**	23.40	5.29*
P × D	3	3.092	17.55**	32.74	7.40**
L × D	3	1.167	6.62**	104.81	23.68**
P × L × D	3	0.756	4.29*	31.01	7.00**
D × NPKL vs. PKL (1)	3	7.209	40.91**	14.64	3.31*
Erroe (b)	32	0.1762	—	4.426	—
Total	59	—	—	—	—

(1)Non-orthogonal comparison
*Denotes significance at 5% level
**Denotes significance at 1% level

538 p.p.m. in the 18-24 inch layer. The contribution of calcium phosphates to total phosphorus increased from 41.1 per cent in the surface layer to 88.4 per cent in the 18-24 inch layer. Aluminium phosphate was highest in the 0-6 inch layer and accounted for 5 per cent or less of the phosphorus in the sub-surface layers. Iron phosphate concentration was negligible for all layers. "Residual phosphates", which are comprised of occluded iron and aluminium phosphates, formed a substantial percentage of total phosphorus in the surface soil. Organic phosphorus decreased with depth of soil profile.

In Table 3 is given the average yield of oats and clover in grams per pot for the different soil layers with various treatments. The analysis of variance (Table 4) revealed that there were highly significant differences between oat yields for the various layers. Yields decreased with depth to the 12-18 inch layer. The application of phosphorus resulted in a significant increase in yields for all soil layers and this effect was most prominent for the 0-6 inch layer. The effect of lime in increasing yields on the 0-6 inch layer was only significant in presence of added phosphorus. Nitrogen applications increased yields on all layers excepting the 0-6 inch. With respect to clover, the analysis of variance shown in Table 4 revealed no significant differences in yields between layers. An examination of Table 3 showed that phosphorus increased yields on all soil layers excepting the 18-24 inch. Without the application of phosphorus, lime increased yields on the 0-6 inch layer whereas the same rate of lime was excessive for the sub-surface samples and depressed clover yields. Nitrogen in the presence of added lime and phosphorus (cf. treatment 4 vs. treatment 5) did not significantly increase yields on the 0-6 inch nor the 6-12 inch soil layers, but it markedly decreased yields on the 12-18 inch and 18-24 inch layers. There was a tendency towards better check (N + K) yields as depth of soil horizon increased. The different response of oats and clover to fertilization on the four soil layers may be explained by the peculiar requirements of the plants for soil nutrients and by the difference in their root systems.

The changes in pH for the different soil layers with and without the application of lime (treatment 2 vs. treatment 4) at the time of harvest are shown in Table 5. Changes in pH of the soil on addition of lime were similar for both crops, varying from a difference of 1.40 to 2.15 for oats, and 1.60 to 2.30 for clover. The 6-12 inch soil layer differed strikingly in its increase in pH from the other soil layers for both crop. This suggested that at the 6-12 inch layer there was less resistance in effecting a change in pH. Such a condition would be of importance when the soil in its natural state in the field is considered; for liming of the surface soil with its attendant leaching into the sub-surface soil would ensure a fair degree of acidity correction down to 12 inches where roots of leguminous plants are usually found.

The average phosphorus uptake of the above-ground parts of clover as well as of oats (grain + straw), with various treatments for the different soil layers, is shown in Table 6. In the absence of lime applications (treatment 1) the uptake of native soil phosphorus by the clover crop was least from the 0-6 inch layer and greatest from the 18-24 inch. For all soil

TABLE 5.—THE EFFECT OF LIME ON pH OF DIFFERENT LAYERS AFTER CROPPING

Crop	Depth 1, 0–6″			Depth 2, 6–12″			Depth 3, 12–18″			Depth 4, 18–24″		
	NPK	NPKL	Diff.	NPK	NPKL	Diff.	NPK	NPKL	Diff.	NPK	NPKL	Diff.
Oats	5.20	6.80	1.60	5.60	7.75	2.15	6.35	7.95	1.60	6.60	8.00	1.40
Clover	5.05	6.70	1.65	5.30	7.60	2.30	6.00	7.80	1.80	6.40	8.00	1.60

TABLE 6.—MEAN PHOSPHORUS UPTAKE BY OATS AND CLOVER

	Oats				Clover			
	0–6″	6–12″	12–18″	18–24″	0–6″	6–12″	12–18″	18–24″
	mg./pot	mg./pot	mg./pot	mg./pot	mg./pot	mg./pot	mg./pot	mg./pot
1. NK	3.63	3.67	2.99	4.12	11.20	16.99	25.27	27.32
2. NPK	15.43	13.28	12.10	11.43	20.40	29.58	40.37	31.37
3. NKL (lime)	5.43	6.40	4.63	3.57	21.65	6.18	5.48	6.00
4. NPKL	22.68	15.39	12.50	11.56	25.62	35.87	26.94	32.01
5. PKL	18.38	7.23	4.20	3.25	28.25	35.59	34.29	37.25

layers, the application of phosphorus increased phosphorus uptake in the plant. When the influence of phosphorus applications on uptake for the different layers was assessed by $\frac{\text{treatment 1}}{\text{treatment 2}} \times 100$, response to applied phosphorus was in the order 0-6″> 6-12″> 12-18″> 18-24″. This indicated that the phosphorus-supplying power of the soil increased with depth and correlated well both with the increase in calcium phosphate content as depth increased (see Table 2) as well as the increase in Bray acid-soluble phosphorus (see Table 1). Lime increased the uptake of native soil phosphorus from the 0-6 inch layer but decreased it from the other soil layers. Over-liming of the 6-12 inch, 12-18 inch, and 18-24 inch layers could have caused this. It should, however, be observed that on the addition of phosphorus the depressing effect of lime on phosphorus uptake was significant only for the 12-18 inch layer. A comparison of treatments 4 and 5 in Table 6 for the different soil layers shows that excepting for the 6-12 inch layer nitrogen depressed the uptake of phosphorus by clover. This depressing effect of nitrogen resulted in depressed yields. It has been significant that all factors which tended to limit or increase phosphorus usage by the clover plant affected the yield accordingly. The great importance of phosphorus and its behaviour in relationship to the different soil layers are striking. With respect to oats, variations in the uptake of native soil phosphorus for the different soil layers; as reflected in the values for treatment 1 (Table 6), were not widely different. On the addition of phosphorus (treatment 2) there was a tendency towards decreased phosphorus uptake as depth of soil horizon increased. No doubt the total nitrogen content (native + added) of the various layers is important in this connection. It might be that the rate of nitrogen used in the investigation was not high enough to ensure complete adequacy for all depths. Soil nitrogen decreased as depth increased and it will be noticed that phosphorus uptake from all soil layers was less in the absence of nitrogen—decreasing as depth increased. The addition of lime facilitated the uptake of phosphorus from the 0-6 inch, 6-12 inch and 12-18 inch soil layers, (treatment 1 vs. treatment 3).

The rate of lime used in the investigation appeared to have depressed native soil phosphorus uptake by the clover crop and consequently influenced yields; however, in the presence of added phosphorus, lime depressed clover yields significantly only on the 12-18 inch soil layer. Excepting for the 18-24 inch soil layer, lime depressed neither phosphorus uptake nor yields of oats significantly.

The results of the investigation offer an explanation for the increased hay yields obtained by farmers on the deep ploughing of this soil. It would appear that deep ploughing results in greater quantities of the more soluble calcium phosphates being brought to the surface. The greater requirements of hay crops for phosphorus and calcium as compared to oats, and the ability of legumes to fix their own nitrogen, would mean that deep ploughing should result in good hay yields whereas oats yields would be limited by the lack of nitrogen in the deep ploughed soil.

REFERENCES

1. Bray, R. H., and L. W. Kurtz. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59:39-45. 1945.
2. Chang, S. C., and M. L. Jackson. Fractionation of soil phosphorus. Soil Sci. 84:133-144. 1957.
3. Chang, S. C., and M. L. Jackson. Soil phosphorus fraction in some representative soils. J. Soil Sci. 9:109-119. 1958.
4. Dunn, L. E. Lime requirement determination of soils by means of titration curves. Soil Sci. 56:341-351. 1943.
5. Englebert, L. E., and E. Truog. Crop response to deep tillage with lime and fertilizer. Soil Sci. Soc. Amer. Proc. 20:50-54. 1956.
6. Halstead, R. L., K. F. Nielsen, and A. J. McLean. Phosphorus and potassium supply for alfalfa in soils sampled at different depths. Can. J. Soil Sci. 37:61-70. 1957.
7. Peech, M., L. T. Alexander, L. A. Dean, and J. F. Reed. Methods of soil analysis for soil fertility investigations. U.S.D.A. Circ. 757. Washington, D.C. 1947.
8. Piper, C. S. Soil and plant analysis. Interscience Publishers Inc., New York, N.Y. 1944.
9. Rost, C. O The relative productivity of soil. Soil Sci. Soc. Amer. Proc. 4:281-287. 1940.
10. Sherman, M. S. Colorimetric determination of phosphorus in soils. Ind. Eng. Chem. Anal. Ed. 14:182-185. 1942.
11. Stanford, G., and W. H. Pierre. Soil management practices in relation to phosphorus availability and use. *In* Soil and fertilizer phosphorus in crop nutrition, ed. by W. H. Pierre and A. G. Norman. Academic Press Inc., New York, N.Y.. 1953.
12. Truog, E. M., and A. H. Meyer. Improvements in the Deniges colorimetric method of phosphorus and arsenic. Ind. Eng. Chem. Anal. Ed. 1:136-139. 1929.

CONSERVATION OF SOIL MOISTURE FROM FALL AND WINTER PRECIPITATION[1]

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ABSTRACT

Twenty years' results showed that 37 per cent of the over-winter precipitation at Swift Current was conserved in stubble fields and 9 per cent in fallow. Further analysis showed that rainfall and snowfall were conserved equally well in stubble but that conservation in fallow was mostly from rainfall. Much of the snow was blown from the fallow and accumulated in the stubble.

Fall moisture was also a factor, in that each inch of moisture stored in the soil in the fall reduced the over-winter conservation by approximately 0.2 inch.

Nine years' results with fall cultivation on stubble showed that one-way disking after harvest reduced the winter storage in 3 years out of 9. Apparently any gain in moisture conservation from the removal of weed growth was more than offset by reduced snow accumulation during the winter. Blade tillage in the fall resulted in greater moisture storage at seed-time in 1 year out of 9.

INTRODUCTION

Earlier work at Swift Current showed that about one-third of the precipitation received on stubble land in the fall and winter was conserved for the succeeding crop. Conservation in bare fallow over-winter was much less than this because of snow blowing and spring run-off.

In the present paper, 20 years' results are analysed to show the separate contributions made to moisture storage by rainfall and snowfall received during the late fall and winter. The influences of fall moisture and of different types of fall cultivation are also assessed.

REVIEW OF LITERATURE

The amount of soil moisture stored from winter precipitation is highly variable because of losses from evaporation, snow blowing and run-off. Barnes and Hopkins (1) on the basis of 7 years' experiments with crops grown in tanks at Swift Current, Saskatchewan, found no appreciable increase in soil moisture from snow cover. In a later report Barnes (2) pointed out that the run-off from frozen soil was not all lost, as it accumulated in low places and the water was absorbed after the soil thawed out.

A report by Staple and Lehane (10), based on field sampling on Illustration Stations in southwestern Saskatchewan, showed that winter precipitation, mostly snowfall, was consistently beneficial in stubble but was frequently negligible in fallow. A mean of 33 per cent of the winter precipitation was stored in stubble and only 16 per cent in fallow. Subsequent work on field shelterbelts by the same authors (12) showed that the main gain in wheat yield near tree rows was due to snow accumulation.

Matthews (6) at the Scott Experimental Farm found that snow ploughing in fields to prevent drifting increased soil moisture in the spring from 10 to 30 per cent.

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Thysell (13) at Mandan, North Dakota, showed that three times as much moisture was conserved from harvest to seed-time in stubble as in fallow land. Initial soil moisture content, as well as snow drifting, was an important factor; more moisture was conserved in bare, fall-ploughed stubble than in fallow.

Mathews (5), in a review of moisture storage and its use by spring wheat in the Great Plains, found that cultivation after harvest increased moisture storage in the southern areas, but that plots without fall tillage conserved more moisture in the north. These results were accounted for by differences in snowfall and in weed growth in the two climatic zones.

Power *et al.* (7) in northeastern Montana (1949–56) found that neither fall blading in stubble nor fall chiseling in fallow increased soil moisture or crop yield. Observations indicated that subsurface tillage in stubble after harvest might be useful for weed control under some climatic conditions.

Results from fall tillage in southwestern Saskatchewan (8) depended on the weather experienced during the fall and winter.

OVER-WINTER CONSERVATION IN STUBBLE AND FALLOW 1937-57

Method

Moisture conservation in fallow and stubble for the period 1937-57 was determined by soil moisture sampling to a depth of 4 feet in field plots after harvest and again at seed-time. The sampling was associated with cultural experiments so that the actual size of plot and date of sampling differed somewhat from year to year and between fallow and stubble. Sixteen to twenty sites were sampled most years, four sites being chosen on each of four or five plots. Fewer samples were taken during the war years when some of the sampling had to be omitted. Sub-samples were taken in depths 0–6, 6–12, 12–24, 24–36, and 36–48 inches. Soil moisture contents in per cent by weight were determined by the gravimetric method. Fall and spring samples were taken within a few feet of each other, and the moisture storage determined by subtraction. Available fall moisture was obtained by substracting the wilting percentage from the total moisture content at fall sampling. Wilting percentages were determined partly by the direct method using sunflowers (14) and partly by the desiccator method (4).

Rainfall was measured with the Canadian standard rain gauge (area 10 square inches). Snowfall was estimated by measuring the depth of fresh snow in sheltered sites and multiplying by the mean water equivalent, 0.1 inch of water to 1 inch of snow. These observations were made at the Experimental Farm, a distance of approximately 2 miles from the field plots. Until recently it was not feasible to obtain records over-winter nearer the plot area.

Results

Soil moisture and precipitation data are given in Table 1. Moisture conservation in columns 5 and 9 show a high variability. This was related to the amount of rainfall and snowfall received, but many conditions of soil and weather also contributed to the result. The rainfall was greater for stubble than for fallow because stubble fields were sometimes sampled

TABLE 1.—MOISTURE CONSERVED IN STUBBLE AND FALLOW FIELDS OVER-WINTER

Season	Stubble				Fallow			
	Fall moisture	Rainfall	Snowfall	Conserved	Fall moisture	Rainfall	Snowfall	Conserved
	in.	in.	in.	in.	in.	in.	in.	in.
1936–37	0.19	0	1.77	1.42	0.42	0	1.77	0.78
1937–38	0.68	2.06	5.28	3.46	1.41	0.25	5.28	0.70
1938–39	1.06	1.04	2.85	1.80	5.04	1.04	2.85	—0.66
1939–40	—0.10	1.59	3.01	3.08	4.06	0.93	3.01	1.15
1940–41	—0.51	3.07	2.12	1.64	4.55	0.40	2.12	—0.24
1941–42	0.86	5.80	2.58	3.02	1.44	0.89	2.58	0.14
1943–44	2.33	0.43	2.22	0.93	4.71	0.43	2.22	0.06
1944–45	1.02	2.74	2.94	3.06	4.56	1.34	2.94	0.04
1945–46	2.40	0.87	2.66	0.27	4.49	0.87	2.66	—0.12
1946–47	2.33	0.52	3.88	0.85	3.49	0.52	3.88	—0.09
1947–48	0.29	2.30	4.10	1.00	3.69	2.30	4.10	0.86
1948–49	—0.06	0.29	3.00	1.51	2.82	0.29	3.00	—0.06
1949–50	—0.41	3.95	4.30	2.77	1.15	3.24	4.30	1.64
1950–51	0.11	1.06	6.61	4.41	5.03	0.59	6.61	—0.10
1951–52	4.57	1.44	5.43	0.85	6.16	1.44	5.43	—0.25
1952–53	2.43	1.78	4.69	2.83	3.23	1.78	4.69	1.11
1953–54	1.06	1.23	2.77	1.11	5.93	1.52	2.77	0.28
1954–55	5.68	4.35	3.22	2.55	6.84	5.03	3.22	2.20
1955–56	1.89	0.57	4.95	1.31	5.73	0.99	4.95	0.92
1956–57	0.24	1.27	4.90	2.40	5.07	1.27	4.90	0.19
Mean	1.30	1.82	3.66	2.01	3.99	1.26	3.66	0.43

earlier in the season. In a few cases snowfall received in October and April was included with the rainfall because the ground was unfrozen and the snow melted rapidly.

Negative values for fall moisture in stubble (column 2) were due partly to the surface soil being below the wilting percentage when sampled. In some years, too, the subsoil after harvest may have been dried slightly below the laboratory-determined wilting point. Negative values for moisture conserved in fallow (column 9) usually mean that no water was added to the subsoil over-winter, and the surface was drier at seed-time than at harvest.

The mean moisture conservation in stubble was 2.01 inches and in fallow 0.43 inch. This was 37 per cent of the over-winter precipitation in stubble and 9 per cent in fallow. The mean available fall moisture in stubble was 1.30 inches and in fallow 3.99 inches. From these figures one might expect a negative correlation between fall moisture and conservation. Such a relationship undoubtedly exists because evaporation and run-off losses increase with soil moisture content, particularly when the subsoil is frozen. However, as will be shown later, much of the difference in moisture conservation was due to snow blowing off the fallow and accumulating in the stubble.

The moisture conserved over-winter plus the fall storage give a total of 3.31 inches available moisture in stubble and 4.42 inches in fallow at seed-time. These values are slightly higher than those obtained by Staple and Lehane (11) for the longer period 1925-52. Data in the present paper are high, partly because of above average precipitation during the years 1950-55.

In assessing the relationship between conservation and precipitation, the linear regression was first worked out for both stubble and fallow. These equations are given below where C represents over-winter conservation and P the corresponding precipitation, both in inches of water:

$$\begin{aligned} \text{Stubble } C &= 0.35\,P + 0.08 \\ \text{Fallow } C &= 0.20\,P - 0.55 \end{aligned} \qquad (1)$$

Analysis of variance in Table 2 shows that the regression for stubble was significant at the 1 per cent level and that for fallow significant at the 5 per cent level. The fiducial limits ($p = 0.05$) of the regression coefficient were 0.13 to 0.57 for stubble and 0.04 to 0.36 for fallow. The correlation coefficient for stubble was 0.615 and for fallow 0.511. In other words, 36 per cent of the variability in conservation was accounted for by the linear regression in stubble and 25 per cent in fallow.

The tendency toward higher regression coefficients for stubble compared with those for fallow must be due in part to snow accumulating in stubble and blowing off fallow. Since this effect should not be applicable to the rainfall, it seemed worthwhile to separate precipitation P into its two components. Regression equations including variables S for snowfall and R for rainfall are given below:

$$\begin{aligned} \text{Stubble } C &= 0.38\,S + 0.34\,R + 0.03 \\ \text{Fallow } C &= 0.009\,S + 0.43\,R - 0.15 \end{aligned} \qquad (2)$$

Table 2 shows that separating S and R reduced the error variance significantly on fallow but had little effect on stubble. The regression coefficients for snowfall and rainfall were significant and nearly equal on stubble, whereas the coefficient for snowfall on fallow was far short of significance and that for rainfall was significant at the 1 per cent level. The multiple correlation coefficient was now 0.616 for stubble and 0.702 for fallow.

Apart from effects due to snow blowing, the conservation of snowfall is influenced by fall moisture and depth of frost. A wet frozen soil is relatively impermeable to water, and, when rapid thaws occur, losses are high from both run-off and evaporation. Stubble fields are less susceptible to such loss than fallow because they are usually drier in the fall and the snow cover reduces frost penetration. Available moisture in the soil in the fall, F, was included as a factor in the regression equations to give:

$$\text{Stubble } C = 0.41\,S + 0.35\,R - 0.24\,F + 0.20$$
$$\text{Fallow } C = 0.04\,S + 0.50\,R - 0.16\,F + 0.30 \qquad (3)$$

The additional factor again reduced the residual variance for both types of surface. Multiple correlation coefficients were 0.711 and 0.797 for stubble and fallow respectively. The regression coefficient for fall moisture on fallow was significant at the 5 per cent level whereas that on stubble was just short of significance. The fiducial limits ($p = 0.05$) of these coefficients were for fallow -0.30 to -0.024, and for stubble -0.49 to $+0.012$. Little difference would be expected between the coefficients on the basis of the factors involved. The mean reduction in conservation due to indirect effects of fall moisture would be about 0.3 inch in stubble and 0.6 inch in fallow.

The higher regression coefficient for rainfall on fallow relative to that on stubble is not readily explained. The fiducial limits of 0.30 to 0.71 for fallow and 0.01 to 0.63 for stubble indicate that the difference is not significant. Some additional benefit from rainfall on fallow might be expected in the early spring when the fallow surface is dry but the stubble is still wet from the spring thaw.

TABLE 2.—ANALYSIS OF VARIANCE—OVER-WINTER CONSERVATION IN FALLOW AND STUBBLE FIELDS, 1937–57

Variance attributable to	Stubble			Fallow		
	DF	MS	F	DF	MS	F
Linear regression with Prec. P	1	8.7270	10.94**	1	2.5726	6.37*
Residual	18	0.7974		18	0.4040	
Additional effect, separating P into S & R	1	0.0302	0.036	1	2.2829	7.78*
Residual	17	0.8426		17	0.2935	
Additional effect, adding F to S & R	1	2.9134	4.09	1	1.3994	6.24*
Residual	16	0.7132		16	0.2243	

*Significant at 5 per cent level
**Significant at 1 per cent level

The residual variance shows that 49 per cent of the variability remained unaccounted for on stubble and 36 per cent on fallow. The conservation, C, based on soil sampling would involve a fairly high experimental error. Errors in measurement of rainfall and snowfall would be small compared with the moisture losses involved. Improvement in the measurement of F would not help much; this factor was included because of its indirect influence on evaporation and run-off. Factors not taken into account specifically include: 1) evaporation from bare soil in fall and spring, and from snow during the winter; 2) run-off, which may vary from year to year depending on the nature of winter and spring thaws; and 3) percolation beyond the root zone. Without these losses, of course, the coefficients for S and R would be near unity and that for F would be zero.

More information is needed before the dispensation of winter precipitation can be properly assessed. Evaporation from bare fallow during the summer months at Swift Current was studied by Hopkins (3) and by Staple and Lehane (9). Presumably evaporation losses in fall and spring, when the soil is unfrozen, can be predicted by an extension of this earlier work. Further data are needed on evaporation from snow and the meteorological factors producing spring run-off. The correlation between moisture conservation and mean air temperature over-winter is very low; temperature as an additional variable in the regression equation did not reduce the residual variance appreciably in either stubble or fallow.

Losses from deep percolation are not usually a problem under semi-arid conditions. The mean conservation in summerfallow by seed-time (Table 1) is 4.42 inches of water, whereas medium loam soils will hold 6.5 inches in the 4-foot root zone. However, some loss usually occurs due to slow capillary movement when moisture exceeds 5.5 inches. Varying amounts of moisture were lost by percolation in fallow following June rains during the period 1951 to 1956. Even in stubble in early spring, some moisture passed below the root zone in years such as 1951, 1952, 1953 and 1955. The losses were exceptional, and the amount of water involved was probably small. Usually a good measure of moisture infiltration and storage can be obtained by sampling to a depth of 4 feet in clays and medium loams, and to 5 feet in fine sandy loam.

FALL TILLAGE AND CONSERVATION 1950-58

Fall tillage of summerfallow using damming listers was tested in the late 30's, with the object of holding snow and trapping spring run-off. Tests conducted at 10 stations in southwestern Saskatchewan* for 2 years, 1938 and 1939, showed no significant gains in moisture in listed fields at seed-time. The data and field observations did not give much promise of increased over-winter conservation in fallow through special tillage.

Experiments described here were designed to find the influence of fall cultivation in stubble fields. Gains in soil moisture conservation might result from reduced weed growth and greater moisture penetration.

Unpublished data. Annual reports, Soil Research Laboratory, Swift Current, Sask.

Method

One-way disking and blade-type tillage on stubble after harvest were compared with an uncultivated check for the 9-year period, 1950-58 inclusive. Moisture conservation was determined as described previously, taking soil samples after harvest and again at seed-time. The fall cultivations were part of a large experiment containing eight treatments quadruplicated in a randomized block design. One weakness of the layout was that the one-way disked and bladed plots were placed side by side, randomized with respect to north and south position, and included as a paired plot in the randomization of each block. Snow blowing from the one-wayed plot could lodge in the bladed plot and enhance the moisture there. This must be kept in mind in assessing the results.

The plots were each 80 feet wide by 600 feet long, comprising approximately 1.1 acres. Four soil samples for moisture determination were taken in each plot so that, with four replicates, sixteen samples were available from each of the three treatments. Samples were taken as usual to a depth of 4 feet except in dry years, when a depth of 3 feet was sufficient. Fall and spring samples were taken within a few feet of each other to minimize variations due to differences in soil texture and run-off.

Results

Results of soil moisture sampling for the 9-year period are given in Table 3. Precipitation includes both rainfall and snowfall occurring between the sampling dates. The 35-year average snowfall in the area is about 35 inches or the equivalent of 3.5 inches of water. The average snowfall for the 9 years shown in Table 3 was 45 inches, considerably above the average. The data given for the three treatments in columns 3, 4 and 5 are averages of 16 determinations.

TABLE 3.—EFFECT OF FALL CULTIVATION ON MOISTURE STORAGE

Year	Pre-cipitation	Moisture conserved, fall to spring			Least significant difference	
		One-way disk	Blade	No fall culti-vation	5%	1%
	in.	in.	in.	in.	in.	in.
1949–50	8.25	1.61	2.51	2.77	0.45	0.61
1950–51	7.67	4.78	6.33	4.41	1.05	1.40
1951–52	6.87	0.40	0.58	0.85	N.S.	N.S.
1952–53	6.47	1.86	2.69	2.83	0.66	0.88
1953–54	4.00	0.57	0.78	1.11	N.S.	N.S.
1954–55	7.57	2.27	2.25	2.55	N.S.	N.S.
1955–56	5.52	1.52	2.39	1.21	N.S.	N.S.
1956–57	6.17	1.42	2.67	2.40	0.55	0.74
1957–58	5.37	2.52	2.19	2.48	N.S.	N.S.
9–year av.	6.43	1.88	2.49	2.30		

Variability between individual samples was high because of uneven snow distribution, and run-off into low places in early spring. In extreme cases the depth of water penetration at seed-time varied from 2 feet to over 4 feet. Table 3 shows that L.S.D.'s of the order of 0.6 inch were required for significance between treatments. Snow blowing on to the experimental area from adjacent fallow also caused differences between blocks, or produced interactions between blocks and treatments. Despite these difficulties, it is believed that the relatively large plots used in the experiment gave a better measure of large-scale phenomena such as snow distribution than would be possible in small plots. Border strips between blocks of fallow and stubble would reduce variations due to snow blowing.

The results show that moisture conservation in the one-way disked plot was significantly lower than in the check in 3 years out of 9, viz., in 1950, 1953 and 1957. The moisture conserved in the bladed strip was significantly higher than that in the check in one year, 1951, and it was about 1 inch higher than in the check, although not reaching the 5 per cent level, another year, 1956. The error of the experiment was particularly high in 1956 because of interaction between blocks and treatments. In the other 4 years the differences between treatments were far short of significance. It will be noted that losses with one-way disking did not occur in the years that gains were obtained with blade tillage.

The location of the bladed plot adjacent to the one-way disked plot was mentioned earlier. This might favour the blading, but when the latter showed definite advantage in only 1 year in 9, the result is not likely to mislead. Also, on March 22, 1951, the depth of snow was 15 to 24 inches on stubble land and 7 to 15 inches on fallow. With all stubble completely buried it seems unlikely that the bladed plot was much influenced by additional snow blown from the adjacent plot. In other winters, with less snow or with recurring thaws, the situation might be different.

Discussion

Many soil and weather conditions are involved in moisture conservation over winter. The 9 years' data indicates that fall cultivation of stubble fields should not be recommended in the Swift Current area. Further examination of the data might help, however, in extending the results to climatic zones where the fall and winter conditions are similar to those experienced at Swift Current during specific years of the test.

It is doubtful if weed control by fall cultivation increased moisture conservation appreciably. Weed infestation was not severe; the soil was often dry after harvest and moisture use low. Fall weed growth was presumably less important than at Lethbridge, Alberta, where gains in crop yield from fall cultivation over a 12-year period were attributed largely to the destruction of late-maturing annual weeds before they set seed*. The present discussion applies only to moisture conservation in the current fall and winter period, and not to fall tillage as a weed control measure. In general, the data and observations in Canada are in agreement with those of Power *et al.* (7) in Montana. The influence of fall tillage on weed infestation should be considered further at some locations.

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Fall blading produced a significant increase in conservation in the spring of 1951 under conditions of very high snowfall, little winter thaw and negligible moisture storage in the fall. Conditions were somewhat similar in the near-significant year, 1956, with moderately high snowfall and little thawing, but with 1.89 inches of available moisture in the fall.

The years 1950, 1953 and 1957, in which one-way disked fields conserved less moisture than the check, had above average snowfall (43 to 49 inches), a moderate amount of winter thawing and low to medium fall conservation. Reduced moisture in the disked plots resulted from less snow accumulation where the stubble was turned down. It seems possible, too, that the thawing periods were sufficient to settle the snow in the stubble, thus permitting more to be trapped with successive storms, but not severe enough to cause excessive evaporation or sealing of the soil surface.

In years 1952 and 1955, the former with high snowfall and the latter near average, effects of tillage were possibly erased by very high fall moisture contents. The other two years, 1954 and 1958, had low to average snowfall and they were "open winters" with frequent thaws. In 1957-58 the fall moisture was low and apparently much of the conservation came from early winter thaws. Later in the season run-off and erosion were high for the amount of snowfall received.

REFERENCES

1. Barnes, S., and E. S. Hopkins. Soil moisture and crop production. Can. Dept. Agr. Bull. 130. 1930.
2. Barnes, S. Soil moisture and crop production under dryland conditions in Western Canada. Can. Dept. Agr. Publ. 595. 1938.
3. Hopkins, J. W. Agricultural meteorology: A statistical study of conservation of precipitation by summerfallowed soil tanks at Swift Current, Saskatchewan. Can. J. Research, C, 18: 388–400. 1940.
4. Lehane, J. J., and W. J. Staple. Desiccator method for determining permanent wilting percentages of soils. Soil Sci. 72:429–433. 1951.
5. Mathews, O. R. Storage of water in soil and its utilization by spring wheat. U.S.D.A. Dept. Bull. 1139. 1923.
6. Matthews, G. D. Snow utilization in prairie agriculture. Can. Dept. Agr. Publ. 696. 1940.
7. Power, J. F., T. S. Aasheim, and G. P. Hartman. Spring wheat production and soil and water conservation as influenced by methods of summerfallowing on a Chestnut soil in northeastern Montana. Soil Sci. Soc. Amer. Proc. 22:460–463. 1958.
8. Soil Research Laboratory Progress Report 1948-54. Can. Dept. Agr. 1956.
9. Staple, W. J., and J. J. Lehane. Estimation of soil moisture conservation from meteorological data. Soil Sci. 58:177–193. 1944.
10. Staple, W. J., and J. J. Lehane. The conservation of soil moisture in southern Saskatchewan. Sci. Agr. 32:36–47. 1952.
11. Staple, W. J., and J. J. Lehane. Weather conditions influencing wheat yields in tanks and field plots. Can. J. Agr. Sci. 34:553–564. 1954.
12. Staple, W. J., and J. J. Lehane. The influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield. Can. J. Agr. Sci. 35:440–453. 1955.
13. Thysell, J. C. Conservation and use of soil moisture at Mandan, N. Dakota. U.S.D.A. Tech. Bull. 617. 1938.
14. Work, R. A., and M. R. Lewis. Moisture equivalent, field capacity, and permanent wilting percentage and their ratio in heavy soils. Agr. Eng. 15:355–362. 1934.

EFFECTS OF DIFFERENT CROPPING SYSTEMS AND OF A SOIL CONDITIONER (VAMA) ON SOME SOIL PHYSICAL PROPERTIES AND ON GROWTH OF TOMATOES[1]

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ABSTRACT

Soil physical condition resulting from different cropping systems was examined on a number of New Brunswick soils and compared with that of the adjoining soils which had been under continuous grass.

Continuous cropping to potatoes reduced the percentage of water-stable aggregates and porosity. Other effects of continuous cultivation were a reduction in soil organic matter content, available water capacity and cation exchange capacity.

VAMA (soil conditioner) increased the percentage of water-stable aggregates and the porosity of the cultivated soils. On the continuous-grass soils these properties were not affected. Other effects of VAMA were an increase in cation exchange capacity and a reduction in available water capacity on all soils.

Yields of tomatoes in the greenhouse were lower on the soils which had been cropped continuously to potatoes than on the corresponding soils which had been under continuous grass. VAMA increased yields of tomatoes on the continuous-potato soils. The increase in yield due to VAMA was directly related to increase in percentage of water-stable aggregates and total pore space.

INTRODUCTION

In New Brunswick, the practice of continuous cropping to potatoes is quite widespread. It has been shown (2, 3, 9, 10) for many soils that this practice has an unfavourable effect on soil physical condition and that crop yields are reduced. Since most of the potato soils of New Brunswick contain a fairly high percentage of coarse primary particles (14) they will probably not deteriorate under continuous cultivation to the same extent as fine-textured soils. Also, effects of unfavourable physical condition, such as surface crusting, are probably overcome by the frequency of cultivation of the potato crop during the growing season. No information is available, however, pertaining to the physical condition of these soils and its relationship to crop production.

In order to examine certain physical properties of these soils as they affect plant growth, a project was undertaken in the greenhouse which was designed to (1) determine the effects of different cropping systems on soil physical condition; (2) study the relationship between the conditions resulting from the different practices and crop performance; (3) observe the effect of improving the physical condition of these soils, by means of a synthetic soil conditioner, on crop performance; (4) compare certain physical measurements as criteria of soil physical condition as it affects plant growth.

[1]Contribution No. 4, Canada Department of Agriculture Research Station, Fredericton, N.B.

TABLE 1.—DESCRIPTION OF SOILS

Soil No.	Cropping system	Designation	Texture	Fraction (%) > 2 mm.
1	Potatoes annually for 26 years	Pot. 26	Sandy loam	0
1a	Continuous grass	Cont. grass	Sandy loam	0
1b	Potatoes annually for 26 years with 8 tons manure annually	Pot. 26 (8M)	Sandy loam	0
1c	Potatoes annually for 26 years with 16 tons manure annually	Pot. 26 (16M)	Sandy loam	0
1d	Potato-grain-clover rotation for 26 years	P-G-C 26	Sandy loam	0
1e	Potato-grain-clover rotation for 26 years with 500 lb. lime following potatoes	P-G-C 26 (500L)	Sandy loam	0
1f	Potato-grain-clover rotation for 26 years with 2000 lb. lime following potatoes	P-G-C 26 (2000L)	Sandy loam	0
1g	Alfalfa for 7 years	Alfalfa	Sandy loam	0
1h	Woodlot	Woodlot	Sandy loam	0
2	Potatoes annually for 30 years	Pot. 30	Loam	3
2a	Continuous grass	Cont. grass	Loam	1
3	Potatoes annually for 25 years	Pot. 25	Loam	15
3a	Continuous grass	Cont. grass	Loam	11
4	Potatoes annually for 12 years	Pot. 12	Loam	9
4a	Continuous grass	Cont. grass	Loam	11
5	Potato-grain rotation for 7 years	P-G 7	Loam	16
5a	Continuous grass	Cont. grass	Loam	11
6	Potato-grain rotation for 8 years	P-G 8	Loam	14
6a	Continuous grass	Cont. grass	Loam	15
7	Subsoil	Subsoil	Silt loam	0

MATERIALS AND METHODS

Samples of surface soils were selected from the site of a long-term project conducted at the Canada Department of Agriculture Research Station at Fredericton and from potato fields in the potato-growing areas of New Brunswick. A sample of subsoil of very low aggregate stability was included in order to demonstrate that soil physical condition is a limiting factor in crop yields and that yields can be increased by improving soil physical condition by means of soil conditioners. A description of the soils is given in Table 1. Samples 1 to 1h inclusive were taken from the site of the long-term project at Fredericton; samples 2 to 6a inclusive were selected from potato fields in the potato-growing area; sample 7 is a fine-textured sub-soil. All samples designated by the subscript "a" represent continuous-grass sods from fence-rows adjoining the corresponding cultivated soils.

The samples were air-dried and passed through a screen with a one-half inch mesh. VAMA (vinyl acetate maleic acid copolymer) was the synthetic soil conditioner used. Preliminary tests with different rates of this material applied according to a procedure outlined in a previous paper (5) showed that VAMA at 0.4 per cent increased the percentage of water-stable aggregates in all the cultivated soils, in most cases to values corre-

sponding to those of the continuous-grass soils. Accordingly, all the surface soils were treated with VAMA at 0 and 0.4 per cent. The subsoil received an application of 0.08 per cent, because the results of the preliminary test indicated that this rate would bring it to an aggregation status comparable to the continuous-grass soils.

The soils were fertilized with 6-12-12 fertilizer at a rate equivalent to 3000 pounds per acre, placed in glazed gallon pots and seeded to Red Cherry tomatoes. The experimental design was a randomized block with four replications. After emergence data had been recorded the crop was thinned to 1 plant per pot. Emergence at 7 days, plant height at 30 days, time for two-thirds of the crop to reach maturity, and yield of mature fruit were taken as measures of crop performance. The maturity data are based on two-thirds of the crop because estimates of time required for the complete crop to reach maturity would be influenced by small numbers of late-maturing fruits. When the crop had been harvested, a soil sample for measurement of porosity was taken, with a 3-inch diameter core sampler, from each pot. The remaining soil in each pot was air dried, mixed and sampled for further physical and chemical analysis.

The effects of the different cropping systems and of VAMA on soil physical condition were assessed by measuring the following properties; aggregate size distribution by the method of Yoder (16); total pore space and non-capillary pore space by an apparatus described by Leamer and Shaw (8); available moisture, which was taken as the difference between the moisture equivalent (4) and 15-atmosphere percentage (13); organic matter and cation exchange capacity by methods outlined by Peech *et al.* (11).

RESULTS AND DISCUSSION

Effects of Treatments on Soil Physical Condition

The data (Table 2) show that the physical condition of the cultivated soils has deteriorated significantly as compared to the continuous-grass soils. The deterioration is less marked where the cropping system included manure or a clover crop. Soils 2, 3, 4, 5 and 6 appear to have maintained a higher degree of aggregate stability than Soil 1. The description in Table 1, however, shows that these soils contain a larger percentage of coarse primary particles, which accounts, at least in part, for the apparent difference in aggregate size. It should be noted that, in the determination of aggregation status, no correction was made for primary particles. This correction was omitted because it was felt that inclusion of the primary particles would provide data which would be of more value in studying soil-plant relations than data showing the degree of aggregation of the silt and clay particles.

Where VAMA was applied, percentage of water-stable aggregates and porosity of the cultivated soils were brought to levels very close to those of the adjacent continuous-grass soils. Most of the increase in non-capillary porosity must have been due to a change in pore-size distribution, since the increase in non-capillary porosity is greater than the increase in the total pore space. The significant cropping system x VAMA interactions are explained by the fact that VAMA had very little effect on the physical properties of the continuous-grass soils.

TABLE 2—EFFECTS OF CROPPING SYSTEMS AND OF VAMA ON SOIL PHYSICAL PROPERTIES

Soil No.	Cropping system	% Aggregates >25 mm.		Non-capillary (60 cm.) porosity		Total porosity	
		Check	VAMA	Check	VAMA	Check	VAMA
1	Pot. 26	31	58	13.6	24.5	52.3	60.3
1a	Cont. grass	57	59	30.2	32.0	66.8	68.5
1b	Pot. 26 (8M)	36	51	17.8	30.8	59.0	64.3
1c	Pot. 26 (16M)	38	51	19.1	29.4	57.4	63.8
1d	P-G-C 26	30	50	16.7	23.7	59.3	63.8
1e	P-G-C 26 (500L)	46	54	19.2	28.0	60.8	65.5
1f	P-G-C 26 (2000L)	37	52	15.3	26.9	58.0	64.0
1g	Alfalfa	60	71	30.2	34.5	62.8	63.0
1h	Woodlot	45	50	24.3	31.5	64.5	68.5
2	Pot. 30	43	59	26.0	34.6	59.5	64.5
2a	Cont. grass	56	61	31.3	35.4	65.0	67.5
3	Pot. 25	57	71	21.0	30.5	58.5	66.0
3a	Cont. grass	63	65	32.6	32.9	69.5	70.8
4	Pot. 12	58	72	25.4	33.6	63.0	69.0
4a	Cont. grass	69	71	30.6	32.5	66.5	68.5
5	P-G 7	63	74	26.1	30.9	62.0	64.5
5a	Cont. grass	72	74	34.3	35.6	67.3	70.3
6	P-G 8	69	70	27.1	34.3	61.8	65.3
6a	Cont. grass	78	78	32.2	37.0	65.3	65.3
7	Subsoil	15	43	11.4	19.6	51.3	58.8
	Mean	51	62	24.2	30.9	61.5	65.6
L.S.D. (0.05) for individual comparisons		4.7		2.1		2.5	
F value for cropping systems		119.4**		106.7**		35.3**	
F value for VAMA		381.9**		763.6**		197.7**	
F value for cropping systems × VAMA		12.1**		11.4**		3.4**	

**Significant at 0.01

The differences in organic matter content due to cropping systems (Table 3), although statistically significant, are less than might have been expected. It has been established (7) that the organic matter content of a soil soon comes to equilibrium with a given cropping system. For most of these soils, however, particularly those from the potato areas, the organic matter content of the cultivated soil represents a very high percentage of that on the continuous-grass soils. The fact that the 0.4 per cent VAMA applied was not recovered in the determination of organic matter is of interest. A probable explanation for this is that decomposition of the native organic matter may have been more rapid where VAMA was applied, due to the improved physical condition of the soil.

Available water capacity (Table 3) was reduced by cultivation. This would be expected since this property is closely related to organic matter content. This is the only property which was affected adversely by VAMA. The highly significant reduction due to this material is accounted for to some extent by a decrease in the moisture equivalent, but for the

TABLE 3.—EFFECT OF CROPPING SYSTEMS AND OF VAMA ON SOIL PHYSICAL PROPERTIES

Soil No.	Cropping system	Moisture equivalent		15-Atmosphere moisture		Available water capacity		Organic matter (%)		Cat. exchange capacity (m.e./100 grams)	
		Check	VAMA	Check	VAMA	Check	VAMA	Check	VAMA	Check	VAMA
1	Pot. 26	18.2	18.2	6.4	7.3	11.8	10.9	2.1	2.3	9.5	12.8
1a	Cont. grass	27.8	26.8	9.4	10.5	18.4	16.3	4.6	4.7	15.1	16.7
1b	Pot. 26 (8M)	19.5	18.3	7.6	8.7	11.9	9.6	3.1	3.5	14.1	14.6
1c	Pot. 26 (16M)	19.7	18.9	7.0	8.9	12.7	10.0	3.5	3.5	13.5	15.2
1d	P-G-C 26	19.5	19.3	7.2	8.3	12.3	11.0	2.9	2.9	14.0	14.3
1e	P-G-C 26 (500L)	24.3	23.9	8.3	9.3	16.0	14.6	3.5	3.5	14.0	14.9
1f	P-G-C 26 (2000L)	23.4	18.9	6.8	7.9	16.6	11.0	2.9	2.8	13.8	14.0
1g	Alfalfa	17.5	17.4	7.0	8.8	10.5	8.6	3.9	4.0	14.2	14.2
1h	Woodlot	28.4	27.4	9.8	11.4	18.6	16.9	5.7	5.1	18.0	18.4
2	Pot. 30	20.2	19.9	7.2	8.5	13.0	11.4	3.2	3.7	10.8	11.7
2a	Cont. grass	24.4	23.6	9.1	10.5	15.3	13.1	4.3	4.4	12.0	12.9
3	Pot. 25	29.4	29.2	9.5	10.6	19.9	18.6	4.2	4.4	13.9	14.5
3a	Cont. grass	34.0	32.9	12.9	13.9	21.1	19.0	6.9	6.9	16.4	17.0
4	Pot. 12	33.0	32.7	10.5	12.3	22.5	20.4	5.3	5.0	13.8	16.1
4a	Cont. grass	34.8	35.0	11.2	12.4	23.6	22.6	4.7	4.7	14.5	15.4
5	P-G 7	30.0	28.4	11.4	12.3	18.6	16.1	4.3	4.3	14.4	15.7
5a	Cont. grass	32.3	31.7	12.1	14.5	20.2	17.2	5.3	5.7	16.5	16.9
6	P-G 8	28.2	27.9	10.4	12.3	17.8	15.6	4.3	4.3	13.9	14.9
6a	Cont. grass	29.5	27.8	10.3	12.2	19.2	15.6	4.4	4.6	13.9	15.0
7	Subsoil	25.9	26.2	8.4	8.5	17.5	17.7	2.2	2.5	21.1	24.5
	Mean	26.0	25.2	9.1	10.4	16.7	14.7	4.0	4.1	14.3	15.5
L.S.D. (0.05) for individual comparisons		1.9		0.5		2.0		0.1		0.5	
F value for cropping systems		131.9**		69.7**		57.2**		158.2**		375.2**	
F value for VAMA		13.4**		151.1**		77.6**		0.5		432.7**	
F value for cropping systems × VAMA		1.1		1.1		1.4		1.3		12.6**	

** Significant at 0.01

most part by an increase in the moisture held at 15 atmospheres pressure. This decrease due to VAMA was noted by Peters *et al.* (12). It does not agree, however, with the report by Hedrick and Mowry (6) in which they conclude that the available moisture capacity of soil is increased by VAMA. The decrease in moisture equivalent as determined by the centrifuge method can be explained by the fact that the VAMA-treated soils drained more readily. The increase in 15-atmosphere moisture can be accounted for by the increased adsorptive capacity of the VAMA-treated soil.

A reduction in cation exchange capacity of the cultivated soils, as would be expected, was associated with the decline in organic matter. It is interesting to note the highly significant increase due to VAMA. On the basis of the average increase in cation exchange capacity, the contribution of this material is approximately 300 m.e. per 100 grams added to the soil. Similar increases in cation exchange capacity due to VAMA and other polyelectrolytes have been observed by Allison (1).

Effects of Treatments on Crop Performance

The data for crop performance (Table 4) show that emergence was somewhat slower on the cultivated soils. This trend was reversed, however, in the growth of plants as indicated by height measurements at 30 days. The more rapid growth on the cultivated soils is also reflected in the slightly earlier maturity on these soils. VAMA had no effect on emergence, rate of growth or number of days to maturity.

TABLE 4.—EFFECT OF CROPPING SYSTEMS AND OF VAMA ON GROWTH AND YIELD OF TOMATOES

Soil No.	Cropping system	% Emergence at 7 days		Height of plants (cm.) at 30 days		No. of days to 2/3 maturity		Yield of tomatoes gm./pot	
		Check	VAMA	Check	VAMA	Check	VAMA	Check	VAMA
1	Pot. 26	40	68	7.2	6.2	120	123	405	452
1a	Cont. grass	63	75	6.0	6.7	122	121	441	450
1b	Pot. 26 (8M)	75	50	8.2	8.1	121	121	486	499
1c	Pot. 26 (16M)	73	53	7.5	7.2	121	122	457	470
1d	P-G-C 26	38	53	6.5	6.3	120	122	445	460
1e	P-G-C 26 (500L)	43	40	5.5	6.0	124	122	419	464
1f	P-G-C 26 (2000L)	30	60	5.9	6.2	122	123	458	475
1g	Alfalfa	80	65	9.5	7.8	117	119	480	503
1h	Woodlot	55	58	7.1	7.2	121	121	469	474
2	Pot. 30	80	13	11.1	10.1	115	117	469	572
2a	Cont. grass	78	90	7.0	7.1	120	120	525	493
3	Pot. 25	48	33	8.6	8.5	116	117	440	450
3a	Cont. grass	80	48	6.6	6.0	123	122	493	468
4	Pot. 12	15	72	9.5	11.4	118	116	570	667
4a	Cont. grass	88	78	7.7	7.0	117	120	440	426
5	P-G 7	55	50	5.9	6.1	121	121	433	457
5a	Cont. grass	65	63	6.3	6.5	122	121	403	436
6	P-G 8	55	85	6.9	9.0	122	117	402	442
6a	Cont. grass	70	58	7.0	6.0	119	121	480	472
7	Subsoil	20	13	8.7	8.6	117	119	378	452
	Mean	57	56	7.4	7.4	120	120	455	479
L.S.D. (0.05) for individual comparisons		3.5		1.7		3.3		40	
F value for cropping systems		3.4**		10.0**		5.8**		14.1**	
F value for VAMA		0.1		0.10		0.5		19.4**	
F value for cropping systems × VAMA		2.4**		1.1		1.4		2.1*	

*Significant at 0.05
**Significant at 0.01

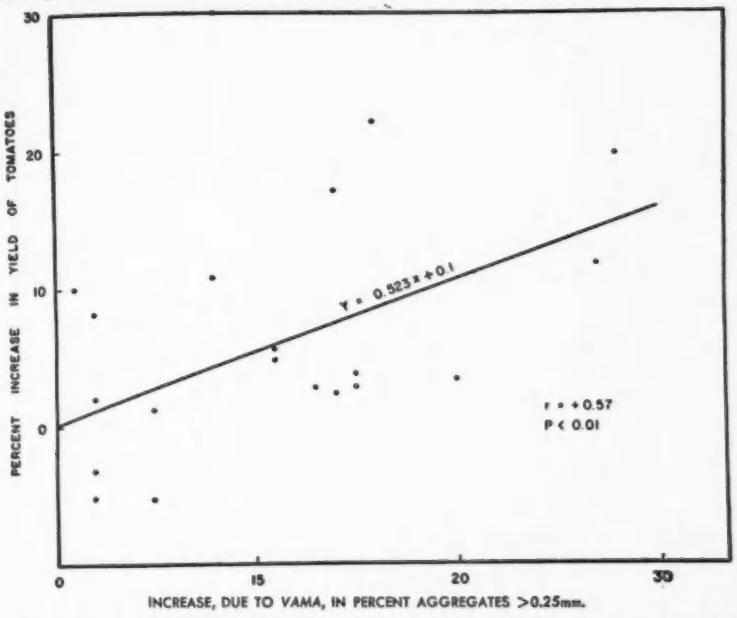

FIGURE 1. Relationship between increase in yield and increase in per cent of aggregates > 0.25mm.

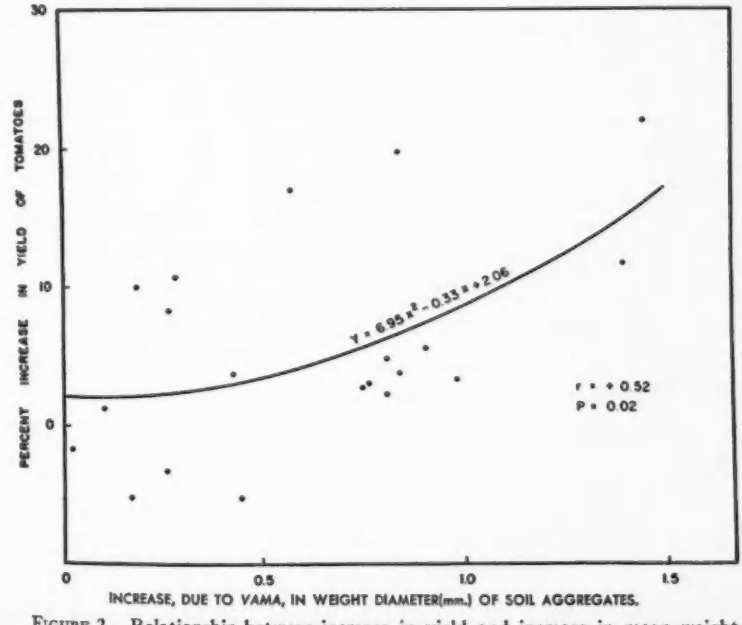

FIGURE 2. Relationship between increase in yield and increase in mean weight-diameter of soil aggregates.

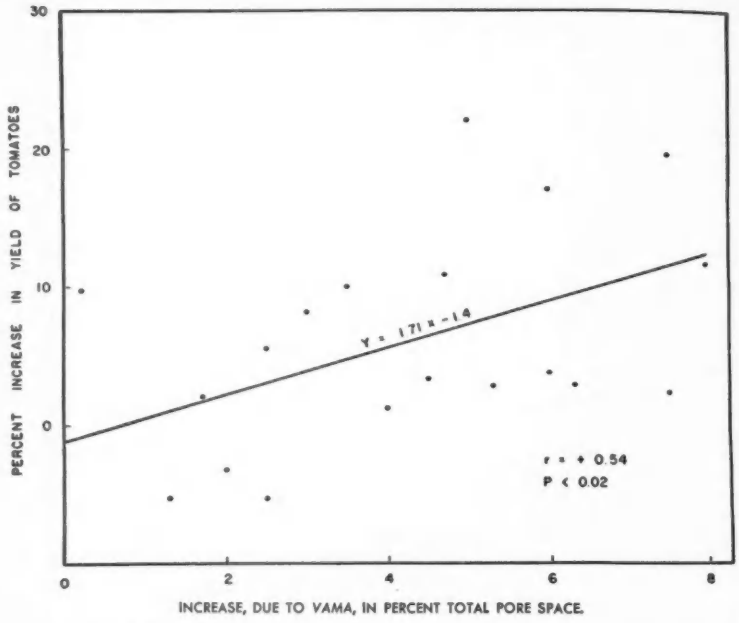

FIGURE 3. Relationship between increase in yield and increase in per cent total pore space.

Yields of mature fruit were, with one exception, lower on the continuous-potato soils than on the corresponding continuous-grass soils. VAMA resulted in an over-all increase in yields which was highly significant. The data show that most of this increase occurred on the continuous-potato soils, particularly those whose physical properties showed the greatest improvement due to VAMA. It is concluded that, under continuous cultivation, the physical condition of these soils has deteriorated to the point where it is a limiting factor in crop production. Under field conditions, however, it is unlikely that yields of potatoes would be affected seriously, since the effect of reduced aggregate size and related properties would be less marked where the crop is cultivated several times during the growing season.

Relationship Between Soil Physical Properties and Crop Yields

Three properties were selected for study as criteria of soil physical condition as it affects crop yields. The relationships are shown in Figures 1 to 3 inclusive.

The relationship between increase in yield of tomatoes and percentage of water-stable aggregates (expressed as per cent aggregates $>$ 0.25 mm.) is shown in Figure 1. The highly significant correlation coefficient indicates that the yield increases are directly proportional to the increase in aggregation. There is considerable deviation from the regression line, however,

which suggests that, in addition to physical condition, there are other factors limiting yields or that the method of measuring aggregate size does not make a sufficiently quantitative measure of aggregate size as it affects crop growth. The latter is the more likely explanation since the harsh treatment to which soil is subjected during wet sieving probably breaks down a considerable percentage of aggregates which are weakly held together but which may be of importance from the standpoint of soil-plant relations.

In Figure 2, aggregate size is expressed as mean weight-diameter (10), in which more importance is attributed to the larger aggregates. This method of expressing results was included because some workers (10) are of the opinion that a soil with large aggregates is more highly aggregated than a soil with the same percentage of smaller aggregates. In this particular case, however, the correlation coefficient of (+ 0.52) between increase in aggregate size and crop response as compared with (+ 0.57) for percentage aggregates > 0.25 mm. shows that there is no advantage in expressing the results as mean-weight diameter. It is suggested that, in some cases, the importance of the larger aggregates is unduly emphasized.

In addition to aggregate stability, other physical properties measured were non-capillary pore space and total pore space. Since these properties are a function of aggregate size, but can be measured without disturbing the natural arrangement of the soil aggregates, it was felt that they might be more useful than aggregate size in assessing soil physical condition as it affects crop performance. This relationship is shown for total pore space in Figure 3. The same relationship for non-capillary porosity with a correlation coefficient of (+ 0.41) did not reach significance at the 5 per cent level of probability. The fact that increase in non-capillary porosity failed to give the same degree of correlation with crop response as increase in total pore space may be attributed to the empirical nature of the procedure used for measurement of non-capillary porosity as compared with the direct measurement used in the determination of total pore space. Total pore space, however, with a correlation coefficient of (+ 0.54) is no more useful in this particular case than percentage of water-stable aggregates as a criterion of soil physical condition.

REFERENCES

1. Allison, L. E. Effect of soil conditioning polymers on the cation-exchange capacity. Soil Sci. 83:391–397. 1950.
2. Baver, L. D. Soil physics. John Wiley & Sons, Inc., New York, N.Y. 1950.
3. Black, C. A. Soil-plant relationships. John Wiley & Sons Inc., New York, N.Y. 1957.
4. Briggs, L. J., and J. W. McLane. The moisture equivalent of soils. U.S.D.A. Bur. Soils Bull. 45. 1907.
5. Doyle, J. J., and A. A. MacLean. Studies with waste sulphite liquor. II. Waste sulphite liquor as a soil aggregating agent. Can. J. Soil Sci. 39:92–97. 1959.
6. Hedrick, R. M., and D. T. Mowry. Effect of synthetic polyelectrolytes on aggregation, aeration and water relationships of soil. Soil Sci. 73:427–441. 1952.
7. Joffe, J. S. Green manuring viewed by a pedologist. Advances in agronomy. VII. Academic Press, Inc., New York, N.Y. 1955.
8. Leamer, R. W., and B. Shaw. A simple apparatus for measuring non-capillary porosity on an extensive scale. J. Amer. Soc. Agron. 33:1003–1008. 1941.

9. Middleton, H. E. Modifying the physical properties of soil. *In* Advances in agronomy. II. (Soil physical conditions and plant growth). Ed. by B. T. Shaw. Academic Press Inc., New York, N.Y. 1952.

10. Neal, O. R. Factors influencing soil structure. *In* Advances in agronomy. V. Academic Press Inc., New York, N.Y. 1953.

11. Peech, M., L. T. Alexander, L. A. Dean, and J. F. Reed. Methods of soil analysis for soil fertility investigations. U.S.D.A. Circ. 757. 1957.

12. Peters, D. B., R. M. Hagan, and C. B. Bodman. Available moisture capacities of soils as affected by additions of polyelectrolyte soil conditioners. Soil Sci. 75:467–471. 1953.

13. Richards, L. A. A pressure-membrane apparatus for soil solution. Soil Sci. 51: 377–386. 1941.

14. Stobbe, P.C., and H. Aalund. Soil survey of the Woodstock area, New Brunswick. Can. Dept. Agr. Publ. 757. 1944.

15. Van Bavel, C. H. M. Mean weight-diameter of soil aggregates as a statistical index of aggregation. Soil Sci. Soc. Amer. Proc. 14:20–23. 1949.

16. Yoder, R. E. A direct method of aggregate analysis and a study of the physical nature of erosion losses. J. Amer. Soc. Agron. 28:337–351. 1936.

EFFECT OF IRRIGATION INTERVAL ON PEAK FLOW REQUIREMENTS IN SPRINKLER IRRIGATED ORCHARDS[1]

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ABSTRACT

Correlations were calculated between the peak flow of water per acre delivered to 174 orchards in the Okanagan Valley in 1958 and the irrigation interval used—that is, the interval between the start of one irrigation and the start of the next irrigation at the same location. Orchards were omitted where seepage water or wilting was in evidence. High negative correlations were obtained between irrigation interval and peak flow. It is concluded that the smaller the field capacity of the soil for moisture, and hence the shorter the irrigation interval, the greater is the required flow of water per acre. This is attributed to greater wastage of water with coarse-textured soils than with fine-textured soils. Some of this wastage is considered to be unavoidable.

REVIEW OF LITERATURE

In most bulletins on irrigation, no mention is made of the effects of soil texture or depth on the peak flow requirements per acre; that is, on the greatest flow required during the heat of the summer. It is usually explained (8, 9) that a sandy soil holds less water than does a silt or clay soil, and that it should on this account receive more frequent irrigations with lesser amounts of water per irrigation. Seldom is it suggested that more total irrigation water is needed on a sandy soil than on a silt or clay soil.

A number of equations have been developed (1, 7, 11) for estimating rates of consumptive use from weather records. The consumptive use values thus obtained are transposed into irrigation requirements with little or no attention paid to the possibility of greater irrigation requirements of sandy soils. In the application of these equations, all soils are apparently treated alike in so far as this problem is concerned.

Exceptions to the general rule have at times appeared. Fortier (2) indicated that gravelly soils need more water than heavy clays. Powers and Lewis (8) pointed out that water is lost by evaporation and by other means every time we irrigate; hence the more frequently we irrigate, the more water is needed. Taylor (10) quoted experimental results in which water wastage and irrigation requirements were greater in sandy soil than in clay soil. McCulloch and Shrunk (5) showed increasing water efficiencies when greater amounts were applied at each irrigation. On the other hand, Israelsen *et al.* (3) found lower efficiencies with greater depths of application, because of greater water wastage.

Rather definite relationships between irrigation requirements and soil texture or irrigation interval have occasionally been suggested. The United States Bureau of Reclamation (6) has recommended duties of water for the Columbia Basin irrigation project ranging from 3.25 feet

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with deep, fine-textured soils to 5.00 feet with coarse-textured soils. Wilcox and Mason (14) reported a reduction in rate of consumptive use as the soil texture became finer and the irrigation interval increased. Based partly on these findings, partly on grower experience, general irrigation recommendations have been made for southern British Columbia (12). The finer-textured the soil, the less is the amount of water recommended. In addition, the B.C. Reclamation Committee, in a long series of briefs, has recommended irrigation water requirements for all of the major arable soil series at present established in the southern interior of British Columbia. These recommendations are based (a) on possible water utilization by the kinds of plant grown; (b) on the soil profile with special reference to soil group, texture and effective soil depth; and (c) on temperature, length of growing season and other climatic factors.

This Review of Literature reveals that some authors consider that soil texture and irrigation interval do influence the irrigation water requirements. As far as can be determined, however, little if any proof of such a relationship has ever been presented. It is the purpose of this paper to present evidence of the effects of irrigation interval on the peak flow requirements for orchard irrigation in the Okanagan Valley.

In this paper, "irrigation interval" means the time in days between the start of one irrigation and the start of the next irrigation at the same location; and "peak flow" means the greatest flow per acre during the heat of the summer, on a steady-flow basis.

PROCEDURE

Data were obtained from over 200 sprinkler-irrigated orchards in the Okanagan Valley in 1958. According to the weather records at Summerland, the summer of 1958 was the hottest in this Station's 44 years of recording. The Okanagan Valley is semi-arid, with average annual precipitation ranging from 9 inches at Osoyoos to 14 inches at Vernon. The irrigation season is usually about 4 months in the south at Osoyoos and 3 months in the north at Vernon. In 1958 it was about 1 month longer than these average periods.

The orchards used for this study were located in the Vernon, South-East Kelowna, Summerland, Penticton, Oliver and Osoyoos districts. The soil zones included in the survey were the black soils of the north Okanagan, the dark brown soils of the central Okanagan, and the brown soils of the south Okanagan (4). In each district, orchards were selected from a wide range of soil textures and depths; hence there was a wide range in the irrigation interval during the heat of the summer. All orchards used contained a high proportion of mature, bearing trees. Low under-tree rotating sprinklers were used in all cases.

Two methods of measuring the rates of water flow per acre were used. In the Vernon and South-East Kelowna districts the water was measured to each orchard over a weir. Daily weir records were obtained from district officials, and these were transposed into rates of full-time flow in Imperial gallons per minute per acre. In the other districts,

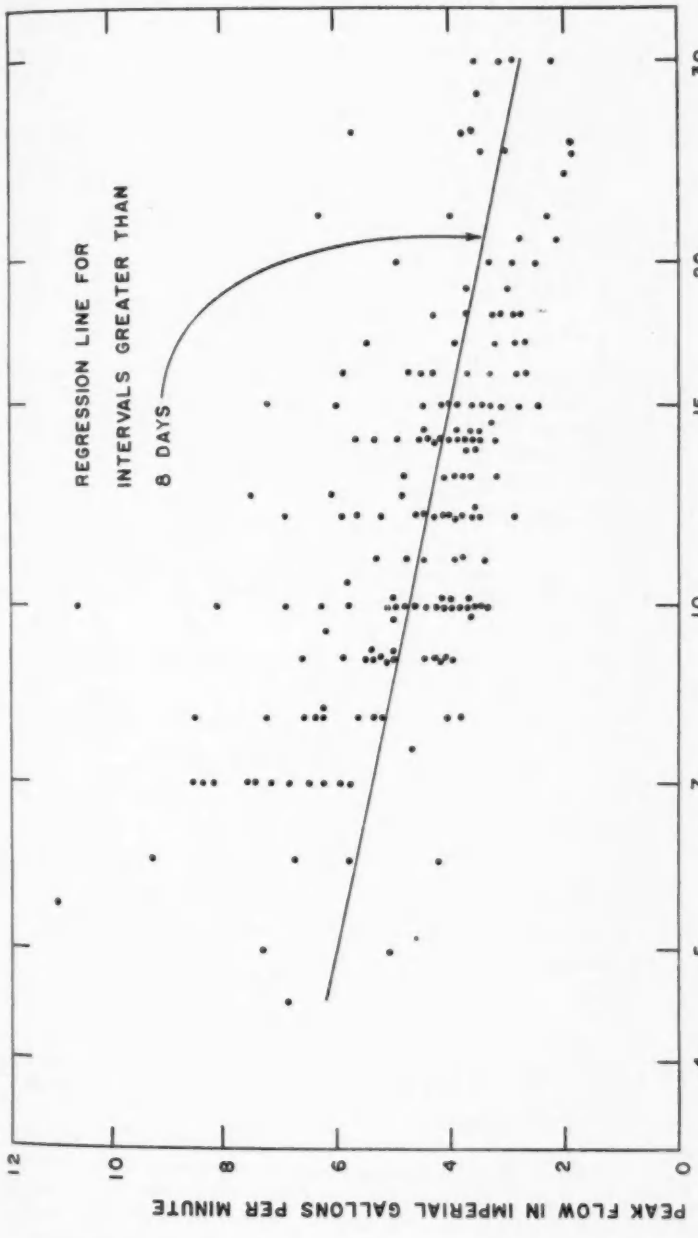

FIGURE 1. Peak flow charted against irrigation interval for 172 orchards. The irrigation interval scale is logarithmic.

records were obtained on nozzle size, pressure at the sprinklers, sprinkler spacing and irrigation interval, which were likewise used to calculate the rates of flow. With each orchard, the average steady rate of flow per acre within each irrigation interval was calculated, and the greatest of these was called the "peak flow".

The records from a number of the orchards were not used for statistical studies. Two main reasons for this were (a) the presence of seepage water from higher up the slopes, and (b) wilting of the trees from drought during the summer. Wilting was due to one or both of two causes: (a) too little water, or (b) too long an interval between irrigations. The number of orchards finally used for these studies was 174.

RESULTS

In Figure 1 is shown a scatter diagram of the peak flow charted against the irrigation interval. The scale of the latter is logarithmic. Omitted from this diagram are two excessively high flow values, and all of those low flow values representing orchards where wilting of the trees occurred. Figure 1 reveals the following information:

1. There was a marked trend toward use of less water as the irrigation interval increased.

2. The lowest peak flows shown tended to decrease as the irrigation interval increased. As far as known, all results used were from orchards that received sufficient water.

3. If the lowest peak flows shown can be considered sufficient, then most of the orchards received more water than necessary.

4. When the soil was coarse textured or shallow, such that the irrigation interval was 10 days or less, the rate of water use was usually exceptionally high. This cannot be blamed entirely on the interval being short or the soil being coarse textured. The fact was that few growers were applying the water for less than 12 hours at a time, and few were using sprinkler nozzles smaller than 1/8 inch. In these sandy soils, therefore, most growers applied much more water at each application than the soil could hold, and the peak flow used was therefore excessive.

Two regression lines were calculated for the values shown in Figure 1: (a) one for all values, and (b) one for all values representing intervals longer than 8 days. These lines were similar in nature, though the former showed somewhat the greater slope. The latter is the one shown in Figure 1.

Correlations between peak flow and irrigation interval were calculated as shown in Table 1. All correlations were negative and highly significant with P = less than 0.01. The highest correlations were obtained using only those values below the regression lines. The indications from this are: (a) that there was a general tendency among growers who used sufficient water to use less water with longer intervals, and (b) that this tendency was even more marked among those growers who used sufficient water, yet who used less than the average for the interval concerned.

TABLE 1.—COEFFICIENTS OF CORRELATION BETWEEN IRRIGATION INTERVAL AND PEAK FLOW

Measure of interval	No. of pairs	Correlation with peak flow
1. Interval in days	174	−0.69**
2. Interval in days, omitting intervals less than 9 days	144	−0.58**
3. Interval in days, using only intervals below No. 2 regression line	87	−0.83**
4. Logarithm of interval	174	−0.65**
5. Log of interval, omitting intervals less than 9 days	144	−0.48**
6. Log of interval, using only intervals below No. 5 regression line	86	−0.81**

**Correlations highly significant, with P = less than 0.01

DISCUSSION

Several questions arise with regard to the data presented in this paper. The first question is: Just what is the relationship among the orchards studied between irrigation interval and soil texture or depth? No definite answer can be given to this question, as no soil samples were taken and no field capacities for moisture were determined. The soil in each orchard was examined visually, however, and the relationship between irrigation interval and soil texture and depth was found to be a close one. Growers have, for the most part, learned how often they need to irrigate to prevent wilting, and this largely determines their frequency of irrigation during the heat of the summer.

The summer of 1958 provided a critical test of the adequacy of the growers' sprinkler systems. Wilt showed up in orchards where it had not occurred since the growers had installed their sprinkler systems. This was because the summer was exceptionally hot and dry. System inadequacy resulted either from inability to apply sufficient water or from inability to get around with the sprinkler lines fast enough. As already noted, orchards that wilted were not used in this study; accordingly, the adequacy of the delivery systems was not considered to be a limiting factor in the 174 orchards used.

This leads to the question as to whether the orchards with the lowest peak flows shown in Figure 1 could have suffered somewhat from moisture deficiency, even though the trees did not wilt. This is possible. It seems safe to assume, however, that where no wilting of the trees was observed the adverse effects on them could not have been severe. In any case, the lower values in Figure 1 should be comparable.

In a previous paper (12), the author has outlined some of the difficulties encountered in trying to use the survey technique for research purposes. In this particular case, the pertinent question is whether the lowest points in Figure 1 really represent those peak flows that were as low as they could be and yet be adequate. If orchard sampling were not thorough, could it not have happened that the lowest peak flows were missed with the shorter intervals but not with the longer intervals? If such were the case, the lowest peak flows might not have shown a negative regression with irrigation interval. In this case, the reverse was actually true. More orchards

were dropped because of wilting with short intervals than with long intervals. The evidence is clear-cut that correlations No. 3 and No. 6 in Table 1 represented basic trends.

Just why less water is needed with finer-textured soils and longer irrigation intervals was not determined in this investigation. There is no evidence to indicate that transpiration is less with finer-textured soils. As indicated in the "Review of Literature", it is more likely that there is some unavoidable water wastage at each irrigation, and that the more frequently we irrigate the greater is this wastage in proportion to the amount of water used by the plants. With sprinkler irrigation there is wastage by evaporation of water in the air, by interception by plant leaves, by evaporation from the soil surface, and by drainage into the deeper subsoil. With surface methods of irrigation there is also wastage by tailings water.

There is a real need to relate water requirements more accurately to the irrigation interval and to the available moisture capacity. It has not been found possible, in this investigation, to work out basic equations using the survey technique. More accurate procedures will have to be used to accomplish this purpose.

ACKNOWLEDGEMENTS

The author wishes to acknowledge assistance given by the District Horticulturists and the Irrigation District officials in which the orchards were located, and co-operation provided by the many growers who participated in the project.

REFERENCES

1. Blaney, H. F., and W. D. Criddle. Determining water requirements in irrigated areas from climatological and irrigation data. U.S. Dept. Agr. Bull. SCS-TP-96. 1950.
2. Fortier, S. Orchard irrigation. U.S. Dept. Agr. Farm Bull. 1518. 1927.
3. Israelsen, O. W., W. D. Criddle, D. K. Fuhriman, and V. E. Hansen. Water-application efficiencies in irrigation. Utah Agr. Expt. Sta. Bull. 311. 1944.
4. Kelley, C. C., and R. H. Spilsbury. Soil survey of the Okanagan and Similkameen valleys, British Columbia. British Columbia Dept. Agr. Survey Rept. 3. 1949.
5. McCulloch, A. W., and J. F. Schrunk. Sprinkler irrigation. Sprinkler Irrigation Assoc., Washington, D.C. 1955.
6. Newell, R. J., W. W. Johnson, A. Patrick, C. S. Scofield, and H. P. Singleton. Columbia Basin joint investigations: Irrigation water requirements, Problems 4 and 5. U.S. Bur. Reclamation Special Rept. 1945.
7. Penman, H. L. Evaporation in nature. Reports on progress in physics 11:366-388. 1948.
8. Powers, W. L., and M. R. Lewis. Irrigation requirement of arable Oregon soils. Oregon Agr. Expt. Sta. Bull. 394. 1941.
9. Smith, G. E. P. Use and waste of irrigation water. Arizona Agr. Expt. Sta. Bull. 101. 1925.
10. Taylor, C. A. Irrigation problems in citrus orchards. U.S. Dept. Agr. Farm Bull. 1876. 1941.
11. Thornthwaite, C. W. An approach toward a rational classification of climate. Geograph. Rev. 38:55-94. 1948.
12. Wilcox, J. C. Use of the survey method in horticultural research. Sci. Agr. 30:137-149. 1950.
13. Wilcox, J. C. Sprinkler irrigation of tree fruits and vegetables in British Columbia. Canada Dept. Agr. Publ. 878. 1953.
14. Wilcox, J. C., and J. L. Mason. Consumptive use of water in orchard soils. II. Effects of evaporating power of air and of length of irrigation interval. Can. J. Agr. Sci. 33:231-245. 1953.

NOTE ON AN APPARATUS FOR CONTROLLING SOIL TEMPERATURES

Temperature of the soil has a profound influence on the metabolic processes in plant roots. A number of studies have been conducted on the effects of temperature on plants, but most of these have been performed in chambers where the temperature of the soil was the same as that of the foliage.

This note describes apparatus that has been developed and used successfully to control soil temperature independent of foliage temperature for plant nutrition investigations.

DESIGN

The units, of which there are four, are large water baths. The method of controlling soil temperatures is the same as that used by Jones *et al.* (1). The basic construction of the four baths is similar, differences being in provision for temperature control. Temperatures of ± 7 to 10° F. of 80°, 67°, 54° and 41° were provided for. Figure 1 shows a cross-section view of the high temperature bath.

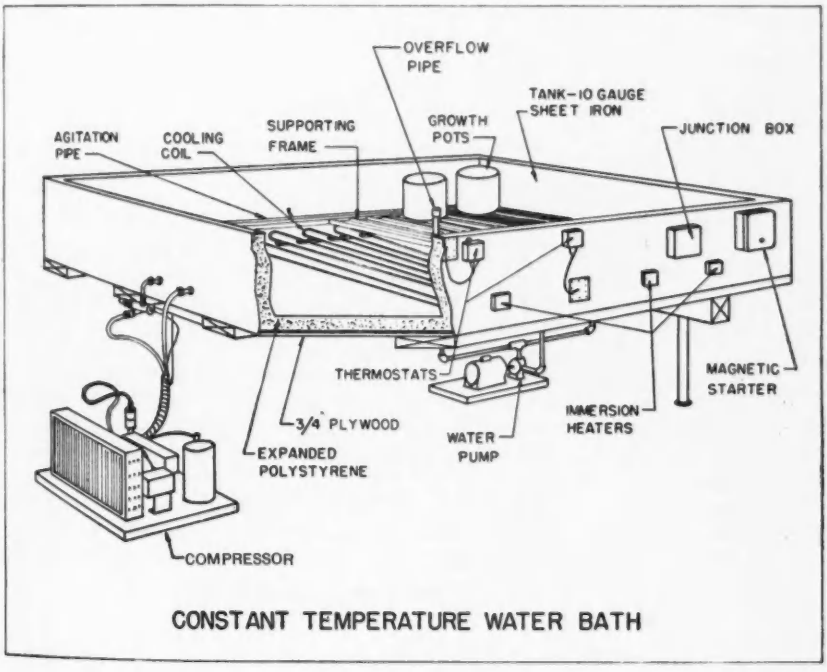

FIGURE 1. Cross-section view of high-temperature bath.

The metal on the inside of the tanks is 10-gauge sheet iron coated with a tar-base material to inhibit rusting. The exterior is galvanized iron. There are 2 inches of rigid expanded polystyrene insulator between the two walls. The interior dimensions of the baths are $7\frac{1}{2}$ feet $\times$ $4\frac{1}{2}$ feet $\times$ $1\frac{1}{4}$ feet. An overflow stand pipe for adjusting the water level is located in the centre of the tank. Removable frames made of aluminum were built to hold the containers of soil off the bottom of the tank, leaving a 4-inch space for refrigeration coils and providing "unused" water for buffering against rapid temperature fluctuations.

TEMPERATURE CONTROL

Copper refrigeration coils of 5/8-inch diameter, located on the bottom of the tank, lead out to a refrigeration unit of sufficient capacity to handle the heat load for the temperature required.

Immersion-type heaters are located in the walls of those tanks requiring them. Separate thermostats are used to regulate the heating and cooling systems in the tank, and give control within $\pm$ 1/2° F.

Table 1 shows the combinations of heating and cooling elements in each tank.

TABLE 1.—HEATING AND COOLING EQUIPMENT FOR THE TEMPERATURE BATH

Temperature of bath °F.	Refrigeration		Heating	Thermostats	
	Size of compressor H.P.	Length of 5/8" coil, ft.	Number of 500 w. elements	Cooling	Heating
80	$\frac{1}{2}$	75	10	1	1
67	$\frac{3}{4}$	100	4	1	1
54	1	125	0	1	0
41	$1\frac{1}{2}$	150	0	1	0

A hydraulic agitation system is used to circulate the water. In the bath itself this consists of a 3/8-inch copper pipe attached to the wall of the tank. This pipe has 1/16-inch perforations spaced at regular intervals and bored to direct the water downward over the heating and cooling elements.

The water in the tank is led out through pipes in the bottom to a 3/8-inch mechanical seal, rubber impeller pump. This pump delivers about 1.8 gallons of water per minute at about 20 pounds pressure to the perforated pipes.

SOIL INSULATION

Sand, vermiculite and beaded expanded polystyrene, all at a thickness of 3/4-inch, were tested for insulation of the soil. Sand was found to be the poorest and polystyrene the best insulator. The superiority of polystyrene became greater at the lower temperatures.

The use of plastic containers for the soil has essentially eliminated the problem of heat transfer which occurred in the walls of glazed clay pots.

REFERENCE

1. Jones, L. R., James Johnson and James G. Dickson. Wisconsin studies upon the relation of soil temperature to plant disease. Wisc. Agr. Exp. Sta. Res. Bull. 71. 1926.

—D. J. COOPER,
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December 2, 1958

NOTE ON A FERTILIZER PLACEMENT SEEDER

The plot seeders commonly used for field testing of fertilizers with grain crops place seed and fertilizer together in the soil. However, it was observed that nitrogen fertilizers placed with the seed of flax delayed and reduced emergence in relatively dry seedbeds. Other workers (2, 5) have noted this effect from fairly light applications of fertilizers with the seed of oats and wheat.

This deleterious effect would probably be eliminated by placing fertilizer in a band away from the seed. Because of the expense and time involved in constructing seeders at present designed for this purpose (1), a 4-row plot seeder of the type described by Kusch *et al.* (3), mounted on a Bolens Ridemaster Model 35AA garden tractor, was modified for use in fertilizer placement.

The two outside double-disk openers and supporting arms were removed from the 4-row plot seeder and hoe-type openers and supporting arms (Figure 1) from a John Deere "LZ-A" mulch hoe drill were mounted in front of the two remaining disk openers. The lower portion of the hoe openers was reduced to 1 inch in width and the width of the opening to 3/4 inch. The hoe openers are suspended in front on slides which provide lateral adjustments of 0, 1 and 2 inches away from the disk openers. The rear suspension provides vertical adjustments of 0, 1 and 2 inches below the disk openers. Details can be seen in Figures 2 and 3. Delivery tubes from the two outside "V" belts are connected to the hoe openers. The number of drive wheels on the garden tractor was increased from two to four to provide adequate traction.

FIGURE 1. Hoe opener and supporting arms after modification.

FIGURE 2. Top view of hoe opener assembly.

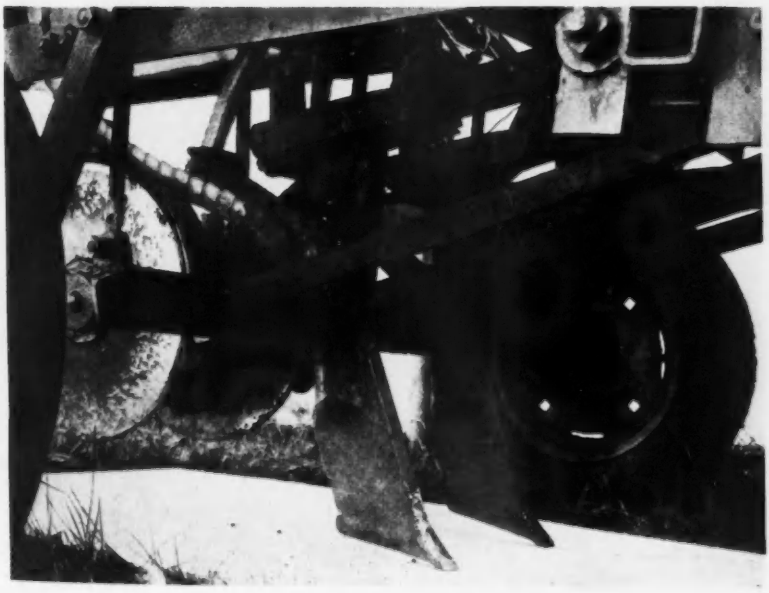

FIGURE 3. Side view of hoe openers and disk openers.

To band fertilizer away from the seed, fertilizer is applied through the hoe openers and the seed is sown through the two disk openers. The lateral and vertical adjustments of the hoe openers allow fertilizer to be banded from 0 to 2 inches below the seed in combination with distances of 0 to 2 inches to the side of the seed. To band fertilizer with the seed, fertilizer and seed are spread together on the two centre "V" belts and applied together through the disk openers. For broadcast applications the feed tubes are disconnected from the hoe openers and the fertilizer falls on the soil surface.

The seeder was found to perform satisfactorily in deeply cultivated, firm seedbeds. Frequent measurements showed that the seed and fertilizer were placed in the soil in the desired proximity to each other. Ten to twenty seconds are required to change settings on the drill to a different placement.

REFERENCES

1. Directory—Special fertilizer application machinery and devices used in research. National Plant Food Institute, Washington, D.C. 1956.
2. Guttay, J. R. The effect of fertilizer on the germination and emergence of wheat and oats. Mich. Agr. Expt. Quart. Bull. 40:193–202. 1957.
3. Kusch, A. G., *et al.* A four-row power plot seeder. Sci. Agr. 30:201–208. 1950.
4. Magee, A. I. Tractor-mounted four-row plot seeder. Sci. Agr. 31:120–121. 1951.
5. Olson, R. A., and A. F. Dreier. Fertilizer placement for small grains in relation to crop stand and nutrient efficiency in Nebraska. Soil Sci. Soc. Amer. Proc. 20:19–24. 1956.

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A STATISTICAL COMPARISON OF LABORATORY METHODS OF DETERMINING THE PERMANENT WILTING POINT OF SOIL[1]

Several authors have reported statistical results of tests on laboratory methods of determining the wilting point. No report is known to the author, however, comparing the standard errors of estimate by the different methods.

Soil samples were taken at a depth of 1 to 2 feet in orchards, to a total of 125 samples. The soils varied in texture from sand to clay. They were all brown soils, so their profile development was not marked and their organic matter content was low. Permanent wilting points were determined by the sunflower method. This was done in glass jars to make certain of complete root distribution. Permanent wilting of the first two true leaves was used as the required degree of wilting. Laboratory determinations were made as follows: (a) percentages of sand, silt, clay and colloid, by the Bouyoucos hydrometer method (1); (b) moisture equivalent; (c) settling volume by the method of Wilcox and Spilsbury (4); (d) hygroscopic coefficient by a modification of the method of Hutcheon (2); and (e) 15-atmosphere percentage using the pressure membrane apparatus (3).

A summary of the correlations and errors obtained is given in Table 1. The most reliable method was found to be the 15-atmosphere per cent. It was, moreover, much easier to determine than its "runner-up", the hygroscopic coefficient.

The 15-atmosphere per cent was not found to be synonymous with the wilting point. The safest procedure found was to use the regression line between the two. In this case the equation was as follows:

$$\text{Wilting point} = -0.662 + 1.016 \times \text{15-atmosphere per cent.}$$

[1]Contribution No. 13 from the Canada Research Station, Summerland, B. C.

TABLE 1.—CORRELATIONS AND ERRORS IN LABORATORY METHODS OF DETERMINING THE WILTING POINT

Method used	Coefficient of correlation*	Standard error
Per cent sand (c)**	−0.77	1.84
Per cent silt	+0.35	2.80
Per cent clay	+0.62	2.28
Per cent colloid	+0.88	1.98
Moisture equivalent (c)	+0.78	1.71
Settling volume (c)	+0.86	1.44
Hygroscopic coefficient	+0.96	0.88
15-atmosphere per cent	+0.99	0.50

* Coefficient of correlation with the permanent wilting point.
** (c) indicates a curved regression line. Those not marked thus had straight regression lines.

REFERENCES

1. Bouyoucos, G. J. An improved type of soil hydrometer. Soil Sci. 76:377–378. 1953.
2. Hutcheon, W. L. The relation of clay and organic matter to soil moisture equilibrium points. Sci. Agr. 23:4–16. 1942.
3. Richards, L. A. Pressure membrane apparatus, construction and use. Agr. Eng. 28: 451–454. 1947.
4. Wilcox, J. C., and R. H. Spilsbury. Soil moisture studies. II. Some relationships between moisture measurements and mechanical analysis. Sci. Agr. 21:459–472. 1941.

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Erratum:

In the paper entitled "Effects of thiourea, ethyl urethane and some dithiocarbamate fungicides on nitrification in Fox Sandy Loam", by Jacques, Robinson and Chase, published in the August, 1959, issue (Vol. 39, No. 2), on page 236, under "Materials and Methods", second paragraph, the first sentence should read: "Fifty-gram portions of the **2-5 mm.** crumb fraction, etc."